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Boxing Practitioners Physiology Review: 2. Systemic Responses and Adaptations

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Abstract

The present journal paper is the second of the three parts of a whole boxing practitioners physiology review. It is related to the boxing practice-derived systemic responses and adaptations. The first part of the review has dealt with kinanthropometric parameters, skeletal muscle recruitment and ergometry. The following and third part of the review is going to deal with dietary supplementation, weight control, recovery, altitude, faith, life expectancy, gender and childhood. Search engines and printed documents have helped gather the information that have been commented in the present and second part: responses and/or adaptations relating to 1) metabolism, 2) skeleton, 3) nervous system, 4) endocrine system, 5) cardiovascular system, 6) urinary tract and 7) pulmonary system. Detailed titles and subtitles of this part of the review are found at the end of the journal paper introduction. The main teachings from the present journal paper may be acquired through the consultation of the tables and figures that are positioned in the text, not forgetting the reminders and advice(s) that appear at the end of each of the seven parts of the journal paper (2.1.6., 2.2.2., 2.3.2., 2.4.2., 2.5.4, 2.6.4. and 2.7.3.).

Keywords

Boxing, Integrative Physiology, Martial Arts, Molecular Physiology, Musculoskeletal Physiology

1. Introduction

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 legal targets.

The legal targets comprise the 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.

When, besides the fists use, that of other body parts (elbows, knees, shins and/or feet) is allowed, boxing is referred to, as may be the case, as Thai boxing, American boxing or French boxing.

Physiology is a biological science that deals with living organisms functions.

Boxing physiology deals with reciprocal influences of boxing practice and boxing practitioners' functions.

The review concerned here deals with physiology of boxing practitioners. The present article is the second part of the whole review. It is related to systemic responses and adaptations. The first part of the review has already been published and has dealt with kinanthropometric parameters, skeletal muscle recruitment and ergometry [1].

Available and pertinent information on boxing practitioners' physiology has been gathered and commented, as was the case in the first part of the review [1].

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

2. Systemic Responses and Adaptations

While a response is something that is done as a reaction to something that has happened [2], an adaptation is the modification of an anatomical structure or a reaction to make them suitable to a new situation [3]. Responses and adaptations are presented below as systemic because their study is approached by organ systems so as anatomical structures to be related to functions.

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. Metabolism while Boxing

Several chemical reactions may take place or be modified in the boxer's organism as a result of boxing activity. Together, those reactions are referred to, below, as metabolism.

2.1.1. Aerobic Power

Aerobic power is a physiological variable which best overall measure is the maximal oxygen uptake ($\dot{V}O_2$ max) [4]. $\dot{V}O_2$ max is the maximal ability to deliver oxygen to the tissues of the body [5]: it is described as the greatest amount of oxygen that can be used at the cellular level for the entire body [6]. The $\dot{V}O_2$ max presents an overall picture of the functional integration of the lungs, heart, blood and muscles in maximal aerobic work [4].

Oxygen uptake ($\dot{V}O_2$) measures conveniently energy expenditure in events where energy requirements are met almost entirely by oxidative metabolism [7].

Nevertheless, boxing is an intermittent high-intensity sport which requires repeated short, intense bouts of activity that are separated by times of rest: it is a "stop and go" sport [8].

1) *Influence of Training Levels and* $\dot{V}O_2max$ *Values*

The first three below mentioned studies show an increase in the $\dot{V}O_2max$ values from the most recreational to the most competitive boxing activity. The first study has dealt with volunteers, the second with amateur boxers and the third with top level competition boxers. The trend was expectable as training increases $\dot{V}O_2max$ values [9] [10]. That fact has already been suggested, speaking of tennis player levels of competition and oxygen consumption ($\dot{V}O_2$) [11] as well as of $\dot{V}O_2max$ values of professional and amateur soccer players [12].

In 18 trained volunteers (12 men and 6 women), $\dot{V}O_2$ has been measured continuously during each fitness boxing trial at various tempos (60, 72, 84, 96, 108 and 120 b·min^{-1}). The $\dot{V}O_2$ values ranged from 26.83 to 29.75 ml·kg^{-1}·min^{-1}, which, according to the authors computations, corresponds to 67.7% - 72.5% of the $\dot{V}O_2max$ (41.04 ± 6.5 ml·kg^{-1}·min^{-1}) [13], values shown in **Table 2** and **Figure 1**. It appeared to the authors of the study that boxing speed is not associated with increased oxygen uptake due to the fact that no significant difference ($p > 0.05$) was seen with the consumption between trials despite the increasing tempos. In other words, despite the increasing tempos and the resulting energy

Table 2. Influence of training level on $\dot{V}O_2max$ values.

Training level	$\dot{V}O_2max$ (ml·kg^{-1}·min^{-1})
Fitness boxing trials volunteers	41.04 ± 6.5
Amateur boxers	57.5 ± 4.7
Top level competition boxers	64.7 ± 6.3

a. Maximal oxygen uptake ($\dot{V}O_2max$) has increased from the most recreational to the most competitive boxing activity. b. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

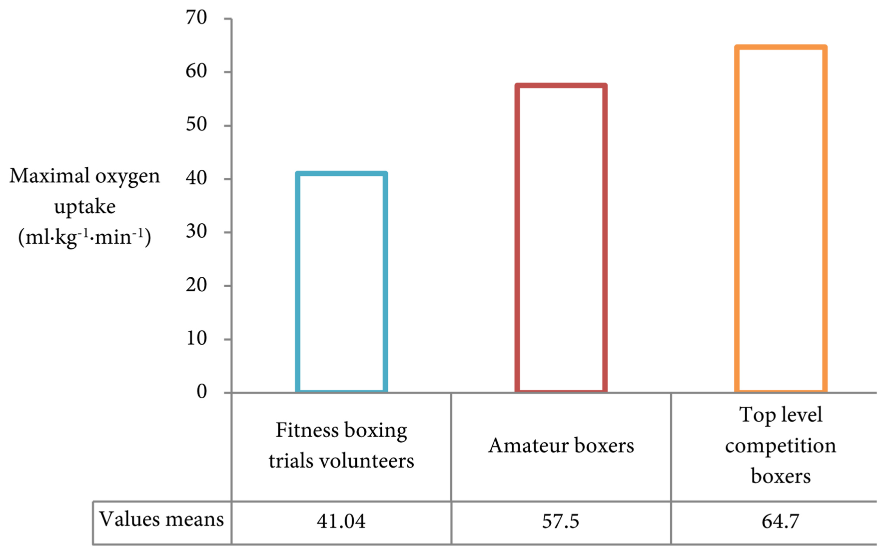


Figure 1. Influence of training level on maximal oxygen uptake values. Maximal oxygen uptake ($\dot{V}O_2max$) has increased from the most recreational to the most competitive boxing activity.

expenditure increases, $\dot{V}O_2$ has remained constant.

That is consistent with earlier research results: once $\dot{V}O_2max$ has been reached, $\dot{V}O_2$ remains constant and additional required energy is produced by a combination of aerobic and anaerobic processes [9]. It is worth signaling that boxing is an intermittent high-intensity sport [8]. Thus, anaerobic systems are expected to provide a significant portion of the energy used while boxing [8]: anaerobic processes contribute for 70% towards boxing total energy expenditure [4], while hence 30% is the contribution of the aerobic process. May the presence of women among the volunteers have had any influence in the lower values? Correction for body weight in all sports does not affect the elite women athletes $\dot{V}O_2max$ which are generally lower than those of men, according to an author [7], while according to another, if either body mass or fat-free mass are incorporated into the mean energy expenditure units, the correction may take place [14].

Another study examined, within middleweight class, the relationship between competition performance and some physiological factors among which $\dot{V}O_2$ [15]. To assess this last, 8 elite Italian amateur boxers [first series of the International Amateur Boxing Association (AIBA) ranking], performed a maximal treadmill test where $\dot{V}O_2max$ measured 57.5 ± 4.7 ml·kg^{-1}·min^{-1}, values shown in **Table 2** and **Figure 1**, and were found positively related (r = 0.81) to boxing competition ranking ($p < 0.05$), as revealed by a Spearman rho correlation analysis. In the AIBA ranking, the first ranked boxer has the highest score gained participating in international tournaments.

The positive relationship between competition ranking and $\dot{V}O_2max$ could be expected as capacity for work depends directly on $\dot{V}O_2max$ [9]. Something worth signaling is that the values shown by the amateur boxers here concerned could have been affected by the use of the treadmill during $\dot{V}O_2max$ measurement. In fact, comparing ergometry modes during submaximal work, Eston and Brodie [16] concluded that at each of different power outputs (49, 73.5 and 98 W), $\dot{V}O_2$ mean 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 that there was no difference between leg ergometry and combined arm and leg ergometry $\dot{V}O_2$ mean values. Meanwhile, boxing activity relies more on upper limbs than on lower limbs, contrary to the treadmill test during which walking and running rely more upon lower limbs than upon upper limbs.

As suggested by Eston and Brodie conclusion [16], boxing moving both upper limbs and lower limbs could possibly have underpinned boxing efficiency in boxers such as Muhammad Ali, Sugar Ray Robinson and Willie Pep.

In French top level male competition boxers, it has been reported the $\dot{V}O_2max$ values of 64.7 ± 6.3 ml·kg^{-1}·min^{-1} [14], values shown in **Table 2** and **Figure 1**.

2) *Influence of Calories and Protein Intakes on* $\dot{V}O_2$ *Values*

In a study aimed to provide information on the requirement of nutrition, especially of protein during rapid weight reduction (lasting 9 days) immediately before competition, subjects were divided into three groups (A, B and C) [17]. At the end of the weight reduction period, for the same submaximal work load, $\dot{V}O_2$ increased significantly in group A, contrary to the groups B and C where no noticeable changes were observed. Group A was the free diet group whose calories and protein intakes averaged 883 kcal·day^{-1} and 0.9 g·kg^{-1}·day^{-1}, respectively, in the second half of weight reduction period. Group B had been imposed 2.0 g·kg^{-1}·day^{-1} of protein in the first half and 1.5 g·kg^{-1}·day^{-1} of protein in the second half of the period. Group C had been imposed 1.0 g·kg^{-1}·day^{-1} of protein throughout the weight reduction period. Groups B and C had been imposed 2000 kcal·day^{-1} in the first half, and 1200 kcal·day^{-1} in the second half of weight reduction period. Nitrogen balance changed to a negative value only in group A, as shown in **Table 2**.

Calorie intake values shown by all the groups (A, B and C) in both the first and the second halves are those of an ordinary person: the intake of the concerned boxers is absolutely (second half) or relatively (first half) reduced, compared to the ordinary value. In fact, the daily energy requirement for a very sedentary man performing only essential functions is about 2000 calories [18], that is 2000 kcal·day^{-1}. Furthermore, in most athletes, total food intake is increased often by more than 1200 kcal·day^{-1} [19].

The Dietary Reference Intakes (DRI) specifies that the requirement for dietary protein for all the individuals, performing exercise or not, aged 19 years and older, is 0.8 g protein kg^{-1} day^{-1} [20]. As for Åstrand, Rodahl, Dahl and Strømme, the daily requirement for an adult is 1g of protein of proper composition per kg of body weight [19]. The values shown are thus normal in groups A and C while in group B they are increased by 100% in the first and by 50% in the second halves of the weight reduction period. Could $\dot{V}O_2$ value be affected by the protein intake increase? That is possible but one must not be surprised of the contrary, taking into account the facts that predominant fuels utilized during exercise are fat and carbohydrate, that protein makes a minor contribution to substrate oxidation during endurance exercise, and that oxidation of amino acid is generally assumed to account for no more than 2% to 4% of exercising energy expenditure [21]. Amino acids result from protein breakdown. As shown in the Table 3, group B $\dot{V}O_2$ remained unchanged at the end of the weight reduction period. The reasons above given stay valid for group C $\dot{V}O_2$, especially as protein intake did not experience any increase from the normal value of 1 g·kg^{-1}·day^{-1}. However, group A has experienced an increase of $\dot{V}O_2$ despite the protein intake normal value of 0.9 g·kg^{-1}·day^{-1}. That may result from two causes.

Firstly, exercising muscle increasingly uses amino acids for fuel as carbohydrate availability decreases [19]. There is there an imaginable possibility of $\dot{V}O_2$ value increase. Here, the boxers concerned whose energy intake should be higher than an ordinary person intake (2000 kcal·day^{-1}) is decreased by 55.9% (883 kcal·day^{-1}).

Carbohydrate availability has actually decreased as fat and carbohydrate contribute about equally to energy supply during light or moderate exercise in the fasting individual [19].

Secondly and more likely, during arm ergometry mode submaximal work, a positive correlation ($r = 0.87$, $p < 0.01$) has been found between $\dot{V}O_2$ and rating of perceived exertion [16]

The increase in $\dot{V}O_2$ at the same submaximal work load found in group A,

Table 3. Influence of calories and protein intakes on $\dot{V}O_2$ values.

Groups	Weight reduction period lasting 9 days					
	Calories intake (kcal·day^{-1})		Protein intake (g·kg^{-1}·day^{-1})		$\dot{V}O_2$	Nitrogen balance
	First half of the period	Second half of the period	First half of the period	Second half of the period	End of the period	End of the period
A (free diet group)		883		0.9	increased	negative value
B	2000	1200	2	1.5	unchanged	unchanged
C	2000	1200	1	1	unchanged	unchanged

a. At the end of the 9-day reduction period, for the same submaximal work load, contrary to the groups B and C, group A showed 1) a significant increase in oxygen consumption ($\dot{V}O_2$) and 2) a change of nitrogen balance to a negative value. b. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

contrary to the groups B and C may possibly result from a physical performance decrease due to a low intake of calorie during the weight reduction period. The submaximal work may have turned more overtaxing in the group A conditions of reduced energy intake, with the resultant increase in the rating of perceived exertion value.

3) *Influence of Moderate Altitude on* $\dot{V}O_2max$ *Values*

Performance reduction with increasing altitude is already evident at an altitude of about 1200 m for heavy exercise that engages large muscle groups for about two minutes or longer [19]. Deleterious effects of high altitude on performance are attributable to the atmospheric oxygen partial pressure decrease in the inspired air and are experienced by the athletes as soon as the altitude exceeds 2000 m [10]. So, with increasing altitude, barometric pressure decreases and $\dot{V}O_2max$ decreases as well [10].

Ordinarily, hypoxia is the usual stimulus for erythropoietin secretion [19], what causes blood erythrocytes number increase (erythropoiesis), with the resulting increase of both blood oxygen transport capacity and $\dot{V}O_2max$ [10]. Iron is essential to hemoglobin synthesis which in turn is indispensable to erythropoiesis [22].

At high altitude, a prolonged stay produces acclimatization to oxygen pressure in the inspired air which consists among other things in erythrocytes concentration and hemoglobin concentration increases, increases which are rapid the first days and slow next [10].

An increase in $\dot{V}O_2max$ value is therefore expectable from the acclimatization. In a healthy person, erythropoietin administration stimulates erythropoiesis, what increases blood oxygen transport capacity [23]. Erythropoietin administration bears thus similarity to altitude training of a sportsperson performing long-lasting exercise tasks [23].

As iron is essential to hemoglobin synthesis and erythropoiesis [22], and as acclimatization may in some cases result among other things in increase of $\dot{V}O_2max$ value which was previously decreased by high altitude [10], is it unsound to expect a possible influence of iron supplementation on athletes $\dot{V}O_2max$ values after training not at high but at moderate altitude (1800 m) during a short stay (18 days)? In other words, is it unsound to expect such iron influence at a post-erythropoietin stage?

The moderate altitude of 1800 m failed to change the $\dot{V}O_2max$ neither in placebo group nor in the group treated with ferrous-glycine-sulfate (1335 mg equivalent to 200 mg elementary iron daily) at the end of 18 days of endurance training by members of the national German boxing team, as revealed by an incremental treadmill test [24].

Moderate instead of high altitude may have contributed to the failure of the altitude to affect $\dot{V}O_2max$ values in each of both groups.

Something worth signaling is that iron absorption adapts itself to the subjects' needs: when the subjects are non-iron-depleted, the excess of administered iron is eliminated with the feces [22]. The athletes here concerned were non-iron-depleted in both groups (placebo and iron supplemented). That explains the failure of iron supplementation to cause any difference of $\dot{V}O_2max$ values between both groups. However, in both groups, acclimatization took place in the form of erythropoietin and reticulocyte increases [24].

2.1.2. Aerobic Capacity

The meaning of the expression "aerobic capacity" varies according to authors. For Harman and Garhammer [25], aerobic capacity is synonymous with aerobic power. According to the two authors, aerobic capacity, also called aerobic power, is the maximum rate at which an athlete can produce energy through oxidation of energy resources (carbohydrates, fats and proteins) and is usually expressed as a volume of oxygen consumed per kg of body weight per minute (*i.e.*, $ml \cdot kg^{-1} \cdot min^{-1}$) [25]. As for Snell, aerobic capacity, often mistakenly used to describe aerobic power, is a measure of oxygen utilization for a given period of time [26]. It is determined by the fraction of the individual's aerobic power that may be utilized for a sustained effort [26].

A well-developed aerobic capacity reflected in the value of 63.8 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$ has been found in senior England international amateur boxers [27].

That $\dot{V}O_2max$ value (63.8 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$) that has been shown by those senior boxers really reflects a well-developed aerobic capacity, taking into account the fact that, as reported in the literature [4], for a range of sports at top level, elite performers of cross-country skiing showed the highest value of 78 - 85 $ml \cdot kg^{-1} \cdot min^{-1}$ while elite performers of baseball showed the lowest value of 40 - 60 $ml \cdot kg^{-1} \cdot min^{-1}$. In fact, the higher the athlete's aerobic power, the greater are the muscle adaptations in order to utilize a given percentage of that power during sustained effort [26]: the higher the aerobic power, the higher the aerobic capacity.

The mean relative $\dot{V}O_2max$ of the heavy weight category boxers has been found lower ($p < 0.05$) than those of lower weight categories in 26 senior national level amateur boxers, as determined by a graded running protocol on a treadmill [28].

That could be expected as heavier boxers generally move slower than lighter boxers. That reminds what has been observed in marathon runners: the faster the runner, the higher the percentage of $\dot{V}O_2max$ required [29]; the higher the speed sustained, the higher oxygen uptake required [7]. As lighter boxers generally fight faster than heavier boxers, it may be expected that the faster (lighter) the boxer, the higher the percentage of $\dot{V}O_2max$ value required (the aerobic capacity).

As aerobic capacity is required for prolonged exertion [30]; and as the higher the aerobic power ($\dot{V}O_2max$), the higher the aerobic capacity, developing $\dot{V}O_2max$ may benefit to increasing one's aerobic capacity. Professional boxers may benefit from that because they are obliged to fight up to 12 three-minute rounds interspersed with one-minute rest. Non-professional boxers fight up to 6 three-minute rounds interspersed with one-minute rest. They also may benefit from $\dot{V}O_2max$ value development.

2.1.3. Anaerobic Threshold and Ventilatory Threshold

Aerobic and anaerobic pathways of energy production are activated simultaneously in all exercise situations [8]. While aerobic metabolism is the dominant pathway of ATP provision during most exercise situations, anaerobic ATP provision plays an important role as an energy buffer when aerobic ATP provision cannot meet the demand for ATP [8].

Anaerobic threshold is the exercise intensity at which anaerobic metabolism complements the regeneration of ATP by aerobic metabolism, according to various authors [31].

If the energy needs of the muscle fibers exceed the capacity of the muscle cells to deliver energy aerobically, a greater proportion of ATP will be provided anaerobically, the consequence of which being an increase in aerobic glycolysis so as to sustain ATP availability [30].

Johnson A.T. [9] mentions definitions of anaerobic threshold, definitions from which may be drawn out indications of the threshold: either a threshold level of lactate in the blood, an increased output of CO_2 from the lungs, an increased rate of respiratory ventilation (linear with work rate below the anaerobic threshold) above the predicted linear value, an increase in respiratory exchange ratio (rate of CO_2 produced divided by rate of O_2 used) above its resting level, or various end-tidal gas partial pressure measures [9].

Anaerobic threshold has been determined as the lactate threshold or as the ventilatory threshold [31]. A more recent threshold is named saliva threshold, has been defined as the point at which the first continuous increase in amylase concentration occurs during exercise [32] and is highly correlated with anaerobic threshold ($r = 0.93$, $p < 0.001$) [32].

Eight elite Italian amateur boxers [first series of AIBA (International Amateur Boxing Association) ranking] performed a maximal treadmill test to assess $\dot{V}O_2$, blood lactate and heart rate at maximal effort, at individual lactate threshold, and at individual ventilator threshold. A Spearman rho correlation analysis revealed that each of the two thresholds was related with boxing competition ranking at its own exercise intensity: individual lactate threshold occurred at 46.0 ± 4.2 ml·kg^{-1}·min^{-1} ($r = 0.91$, $p < 0.01$) while individual ventilator threshold occurred at 28.6 ± 4.2 ml·kg^{-1}·min^{-1} ($r = 0.62$) [15].

Lactate threshold could hence be a better predictor of boxing performance than ventilatory threshold even though lactate threshold has been said to be generally contemporaneous with ventilatory threshold [10]. The gaps shown by the saliva threshold [33] should better be filled as the threshold determination is neither invasive (the case of lactate threshold) nor somewhat subjective (the case of ventilatory threshold). It is worth signaling here that anaerobic threshold is a good predictor of sustained exercise ability [10]. Furthermore, in well trained individuals, even when $\dot{V}O_2max$ values show little additional improvements, endurance capacity values show better improvements with further training [31].

2.1.4. Anaerobic Power Output

The maximum amount of energy that can be transformed during exercise, per unit time, is referred to as the energetic power of the energy system that is used [30]. Power has been expressed as work done per unit time [34].

Anaerobic power output is the contribution of anaerobic systems to the maximal amount of work that is performed during no more than 30 s.

The Wingate Anaerobic Power Test may be used as a measure of the anaerobic power and demands maximal cycling for 30 s on a bicycle ergometer, or alternately repeated intervals of 6 s duration with limited recovery in order to determine a performance-related fatigue curve [30]. Margaria, Aghemo and Rovelli, as for them, designed a stair-run test from which the maximum power output may be calculated [12]. The value below mentioned refers to a mean of power outputs over 30 s [4]. In both the Wingate Anaerobic Power Test and the Margaria, Aghemo and Rovelli stair-run test, muscle substrates expectable to be used during no more than 30 s are ATP, creatine phosphate and glycogen.

At a standardized power output of 15 $W \cdot kg^{-1}$ bodyweight, the mean anaerobic power output over 30 s took the value of 878 W in male boxers who performed a stair run test [4].

Comparison between pre-training and post-training anaerobic power output values may help notice an increase in the variable value. The increase in anaerobic power output value may reflect an increase in the ability to sustain a high intensity work, as has been said for cyclists [30].

2.1.5. Energy Expenditure

To expend is to use or spend a lot of energy…, in order to achieve something [2]. Energy is the physical and mental strength that makes one able to do things [2].

Energy expenditure consists of several measurable components: basal metabolic rate (60%), thermic effect of food (8%), non-exercise activity (7%), and purposeful physical activity (25%) [18].

Thus, energy expenditure refers in the present study to the action of using or spending energy during boxing practice.

In boxing, relative contributions of anaerobic and aerobic processes towards total energy expenditure are: 70% dependence on anaerobic [4] and thus 30% on aerobic processes.

With $\dot{V}O_2$ values ranging from 26.86 to 29.75 $ml \cdot kg^{-1} \cdot min^{-1}$, which correspond to 67.7% - 72.5% $\dot{V}O_2max$, energy expenditure values ranging from 9.8 to 11.2 $kcal \cdot min^{-1}$ have been obtained in 2-minute randomized fitness boxing trials employing 18 trained volunteers (12 men and 6 women: age = 22.0 ± 2.8 years, height = 170.79 ± 7.67 cm, weight = 71.54 ± 12.63 kg) wearing 0.34-kg punching gloves, at various tempos (60, 72, 84, 96, 108, and 120 $b \cdot min^{-1}$) [13]. Assuming that one kcal corresponds to 4186 J [19], fitness boxing energy expenditure values ranged thus from 41.02 to 46.88 kJ·min^{-1}, as shown in **Table 4** and **Figure 2**.

A non-contact boxing training session lasting 60 minutes caused 8 healthy males to expend between 2519 and 3079 kJ in 60 minutes [35]. That corresponds to 41.98 - 51.32 kJ·min^{-1}, as shown in **Table 4** and **Figure 2**. A typical boxing training session lasting 60 minutes causes a person to expend 2821 ± 190 kJ·h^{-1}, that is 47.02 kJ·min^{-1} [35].

Due to the energy cost range of 46 to 60 kJ·min^{-1} found in male subjects, what is signaled in **Table 4** and **Figure 2**, boxing has been classified as a "heavy work" in a classification of sports as light, moderate, heavy and very heavy [4]. The energy expenditure value of 67.4 kJ·min^{-1} with a 148 beats·min^{-1} heart rate value has been reported in boxing practitioners [14].

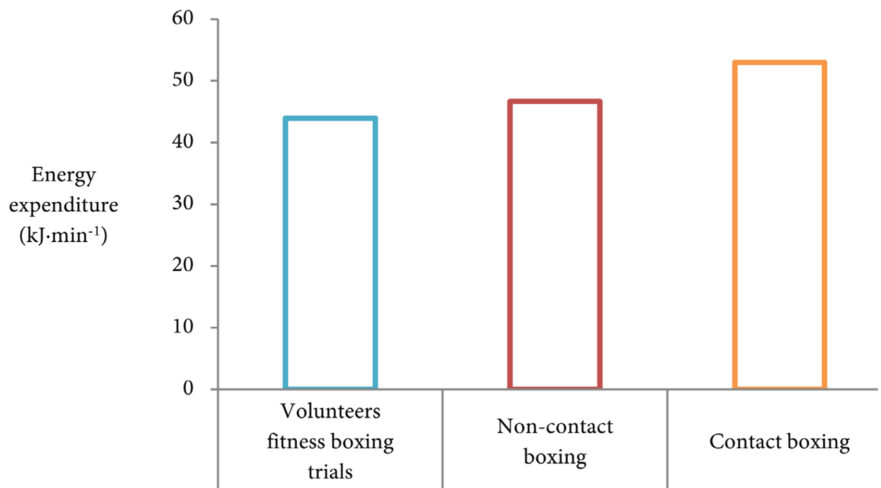
The amount of energy used to perform daily physical activities can vary markedly in different individuals, depending on the type of physical activity [18].

That is reflected in the results reported above. As a matter of fact, the energy expenditure ranges (both lowest and highest values) increase in the following

Table 4. Influence of form of boxing on energy expenditure.

Boxing activity	Energy expenditure (kJ·min^{-1})
Volunteers fitness boxing trials	41.02 - 46.88
Non-contact boxing	41.98 - 51.32
Contact boxing	46.00 - 60.00

a. Energy expenditure has shown a trend to increase, while boxing, from the most recreational to the most competitive form of boxing. b. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.



	Volunteers fitness boxing trials	Non-contact boxing	Contact boxing
Values range means	43.95	46.65	53

Figure 2. Influence of form of boxing on energy expenditure. Energy expenditure has shown a trend to increase, while boxing, from the most recreational to the most competitive form of boxing.

order: volunteers < non-contact boxers < contact boxers. As a matter of fact, the order is from the most recreational to the most competitive and thus from the least energy demanding to the most [14]. Furthermore, the presence of women in the volunteers may have contributed to the lessening of the energy expenditure values [14].

Many sports require repeated short, intense bouts of activity that are separated by times of rest or low activity and are referred to as "stop and go" sports [8]. In the case of boxing, classified as "heavy work", due to the energy cost range found in practitioners [4], the bouts number varies from three to 12, the bouts last from one to three minutes and are interspersed with one-minute rest [36].

Anaerobic systems provide a significant portion of the energy used during the "stop and go" sports, as the required power outputs are high and the time for aerobic energy contributions is short [8]. As for boxing, anaerobic process contributes for 70% towards total energy expenditure [4], while thus 30% is the contribution of aerobic process.

Exercise ability depends on mechanical energy resulting from conversion of chemical energy provided by adenosine triphosphate (ATP) [37]. Skeletal muscle cell ATP store is very insufficient to permit a sprinting lasting more than 5 seconds or an intense aerobic exercise lasting more than 15 seconds, what makes indispensable cell ATP replenishment [8].

Skeletal muscle cell ATP replenishment may derive from aerobic ATP production or from anaerobic ATP production: the glycogenolytic/glycolytic pathways that metabolize carbohydrate and ultimately provide "anaerobic ATP" with production of lactate also provide pyruvate for the oxidation of carbohydrate and aerobic ATP production [8]. In anaerobic ATP production, ATP replenishment from phosphocreatine is considered the first line of defense [8]. In extreme exercise, like all-out sprints lasting longer than 10 to 15 seconds, it is also possible to regenerate a small amount of ATP from adenosine di-phosphate (ADP) in the reaction catalyzed by the near equilibrium enzyme adenylate kinase [8].

The anaerobic production of ATP, or substrate phosphorylation, is required when oxidative phosphorylation cannot provide all of the required ATP: during the transition from rest to exercise, during an increase in power output, and at power outputs above that required for exercise at 100% $\dot{V}O_2max$ [37].

Energy utilization inevitably relates to metabolic changes, such as depletion of substrates and/or accumulation of products, which potentially impair contraction and lead to fatigue [38].

In fact, each of the ATP replenishment process results in ATP hydrolysis so as to allow conversion of chemical energy into mechanical energy, the consequence of which are increases in ADP and inorganic phosphate. Moreover, increase in hydrogen ion (H^+) results from anaerobic glycolysis.

Hypoglycemia, ammonia (sum of NH_3 and NH_4^+), H^+ increase are possible metabolic factors involved in central fatigue (fatigue in which impairment is located in the central nervous system) [38]. Increases in inorganic phosphate, ADP and H^+, as well as muscle glycogen decrease are possible metabolic factors involved in peripheral fatigue (fatigue in which the impairment is located in the muscle) [38].

As boxing practice rely more on anaerobic than on aerobic processes towards total energy expenditure [4] boxers would better postpone fatigue onset 1) by a sound available energy management so as to prevent early depletion of substrates (glycogen) and 2) by training their bodies to tolerate accumulation of products which potentially impair contraction and lead to fatigue (ADP, inorganic phosphate, ammonia, H^+ [38]).

For that, coaches would better, among other things, help their boxers 1) prepare their attacks so as to avoid unsuccessful attack attempts and the resulting energy wastes; 2) master successful landing hook and uppercut punches, which cause less energy loss than successful landed straight punches; 3) defend themselves from attacks by using preferably techniques that avoid contacts with the attacking boxers' body instead of techniques that allow the contact: the former techniques cause the attacking boxers lose uselessly energy, contrary to the defending boxers, while the latter techniques cause the defending boxers lose relatively more energy than the formers; 4) to resort more in one defense movement in which a defense technique is linked up with an attack technique than in performing two movements where a counterattack technique follows a defense technique.

Endurance is the ability to continue doing something difficult or painful over a long period of time [2]. A boxer, lacking confidence in his own endurance, may choose to gamble on a knock-out victory by forcing the pace in the early rounds [4]. That stays valid for a boxer who actually shows a low endurance value.

During a boxing battle, strategy may either be freely adopted throughout the battle or adapted to each new situation.

With the purpose of increasing the chance of winning a boxing bout, one may be obliged to defend and counter more than attack while opposed to a shorter opponent and to restlessly attack while opposed to a taller opponent. The latter strategy may possibly result in energy expenditure higher than that of the former strategy.

During submaximal work, using a combined arm and leg air-braked ergometer, oxygen uptake ($\dot{V}O_2$) has been found higher for arm work alone compared with leg work alone and compared with combined arm and leg work [16]. A difference in energy expenditure level is thus expectable according to the fact that the boxer uses predominantly his arms, his legs or combines arms and legs.

Using a test that incorporated movement patterns similar to those used in cross-country skiing, some findings have been the following: 1) at submaximal work levels, $\dot{V}O_2$ value was significantly lower during the combined arm and leg test comparing with the leg test; 2) maximum oxygen uptake ($\dot{V}O_2 max$) value was not significantly different when comparing leg test to the combined arm and leg test; 3) anaerobic threshold (AT) occurred at 68%, 73% and 76% of $\dot{V}O_2max$ for the arm, the leg and the combined arm and leg test, respectively; 4) although there were no significant differences in $\dot{V}O_2$ and percent of $\dot{V}O_2max$ values, at the anaerobic threshold, between the leg test and the combined arm and leg test, AT was significantly delayed with respect to time and work rate in the latter condition [39].

In order both to reduce oxygen uptake ($\dot{V}O_2$), which contributes to energy expenditure, and to delay anaerobic threshold, and hence the onset of fatigue, it may be proposed that, as far as possible, boxers prepare their attacks as follows: 1) hitting lightly while turning around the opponent, 2) suddenly stop, and then 3) hit hard with the intention either to discourage the opponent from attacking or to knock the latter out. That strategy has been successfully used more than once by Muhammad Ali.

What above mentioned suggests that energy expenditure and its components, aerobic as well as anaerobic, may vary according to the boxer's skills and strategy utilized while boxing.

2.1.6. Reminder and Advices

1) *Reminder*

Oxygen uptake ($\dot{V}O_2$) has remained constant despite the increasing energy expenditure that results from the increasing boxing speed.

During a rapid weight reduction period lasting 9 days immediately before boxing competition, low calorie intake could possibly result in a $\dot{V}O_2$ significant increase, a change of nitrogen balance to a negative value and a physical performance decrease.

Maximal oxygen uptake ($\dot{V}O_2max$) has increased from the most recreational to the most competitive boxing activity: from volunteers, through amateur, to top level competition boxers.

The $\dot{V}O_2max$ value shown by boxers (63.8 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$) reflects a well-developed aerobic capacity.

The mean relative $\dot{V}O_2max$ of the heavy weight category boxers has been found lower than that of lower weight category boxers.

Boxers $\dot{V}O_2max$ failed to be affected despite the acclimatization that took place in the form of erythropoietin and reticulocyte increases at the end of 18 days of endurance training at moderate (1800 m) instead of high altitude.

The mean anaerobic power output over 30 seconds took the value of 878 W in male boxers who performed a stair run test at a standardized power output of 15 $W \cdot kg^{-1}$ bodyweight.

Each of individual lactate threshold and individual ventilatory threshold is related to boxing competition ranking at its own exercise intensity but the former threshold seems to be better predictor of boxing performance than the latter.

In boxing, relative contributions of aerobic and anaerobic processes towards total energy expenditure are: 30% dependence on aerobic and 70% dependence on anaerobic processes.

Energy expenditure and its components, aerobic as well as anaerobic, may vary according to the boxer's skills and strategy utilized while boxing.

Energy expenditure while boxing tends to increase from the most recreational to the most competitive form of boxing.

2) *Advices*

Analysis of data concerned by the present part of the review suggests the following advices.

During rapid weight reduction, insufficient calories intake should better be avoided so as to prevent excessive oxygen consumption ($\dot{V}O_2$), what could possibly decrease pugilistic performance.

Boxers should better box moving both upper limbs and lower limbs than moving only upper limbs so as to prevent excessive $\dot{V}O_2$ consumption.

Boxers should train so as to increase their maximal oxygen uptake ($\dot{V}O_2max$) values as well as their aerobic capacities values, what could possibly improve their abilities to box faster.

Attempts to increase $\dot{V}O_2max$ values by staying at high altitude should better meet the requirements of both adequate altitude and adequate stay duration.

Boxers anaerobic power output values should better be increased so as the boxers become able to sustain a higher intensity work.

When boxing performance is concerned, anaerobic threshold should better be determined using lactate threshold than using ventilatory threshold.

A boxer who lacks confidence in his own endurance as well as the boxer who actually shows a low endurance value could gamble on an early knock-out victory.

Opposed to a shorter opponent, a boxer could choose to defend and counter more than to attack; while opposed to a taller opponent, the boxer could choose to attack restlessly.

Attacks should better be prepared, being landing hook and uppercut punches preferable to landing straight punches.

While defending themselves from attacks, boxers should use techniques that avoid contacts with the attacking boxers' bodies in preference to techniques that allow the contact.

Boxers should better resort more in defense techniques linked up with attack techniques than in counterattack techniques following defense techniques.

2.2. Skeleton Adaptations to Boxing Practice

Skeleton is the structure consisting of all the bones in the human body [2]. Skeletal system consists of bones that serve as a reservoir for calcium and phosphorus and act as biomechanical levers on which muscles act to produce the movements permitted by joints [40].

Bones typically begin to fuse during early adolescence and most bones are fused by the early 20 s [41]. That has to be taken into account while dealing with the results obtained in adolescents versus results obtained on adults.

A synostosis is a joint where bone is connected to bone by bone: the joint no permits any movement [42].

2.2.1. Skeleton Adaptations

1) *Skeleton Adaptations in Adolescent Boxers*

Synostosis in the hand bones and the distal portion of the forearm as well as mineral saturation of the metacarpal bones have been studied in young boxers aged 15 - 17 years old [43]. As adaptive-compensatory changes boxing training-yielded, it has been found, due to specific loading on the hand bones, a decreasing rate of synostosis in the distal epiphysis of the forearm and hand bones. Those changes have been seen by the authors of the study as increased mineral saturation in the young boxers' hand bones that correspondingly results in their increasing resistivity.

A decreasing rate of synostosis means that in the concerned young boxers, it has been found a decreased rate of completely fused constituents of the synostosis that join the distal epiphysis of the forearm and hand bones. What can explain such a situation while it is expected that activity translates into increased loading on the bone and that when bone is loaded or stressed, it tends to build up; bone becomes denser with use [44]? The situation may result from the age of the concerned boxers who were still adolescents. As a matter of fact, bone mineral accrual lags behind longitudinal skeletal growth during adolescence [19].

The noticed increased mineral saturation in the hand bones accompanied with the decreasing rate of synostosis in the distal epiphysis of the forearm and hand bones suggests a redistribution of minerals in the skeleton of the adolescent boxers, specific to the age and to boxing training.

2) *Skeleton Adaptations in Adult Boxers*

Bone quality modification has motivated research workers to carry out studies on adult high-performance sportspersons. Comparison has been made to age-matched male control individuals aged 21 [45] [46]. Bone density measurements of the lumbar spine and left hip have been performed with the aim of knowing the influence of high-performance sports on the bone density in athletes with high demands on weight-bearing of the spine. The bone mineral density (BMD) of the boxers' lumbar spine has been found greater than that of the controls by 17% on the AP view (0.174 $g \cdot cm^{-2}$) and by 19% on the lateral view (0.174 $g \cdot cm^{-2}$) [46], as signaled in **Table 5** and **Figure 3**. The boxers have shown an increase in hip BMD up to 9% and an increase in Ward's triangle BMD up to 7% [45], as also signaled in **Table 5** and **Figure 3**.

Increases in BMD had to be expected as 1) athletes, especially those who are strength trained, have greater bone mineral densities than non-athletes [19], 2) it is through its load-bearing effect on the skeleton that physical activity is the most important influence on bone density and bone architecture [19], and 3) muscular exercise has been found to accelerate the rate of bone deposition [19].

A mechanism underlies the increase in BMD resulting from extreme physical stress: muscle strength and hypertrophy gains increase the force exerted on the

Table 5. Influence of boxing practice on bone mineral density (BMD).

BMD increase in the lumbar spine, compared to that of the controls	
AP view	lateral view
17%	19%
BMD increase in the hip	
up to 9%	
BMD increase in the Ward's triangle	
up to 7%	

a. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

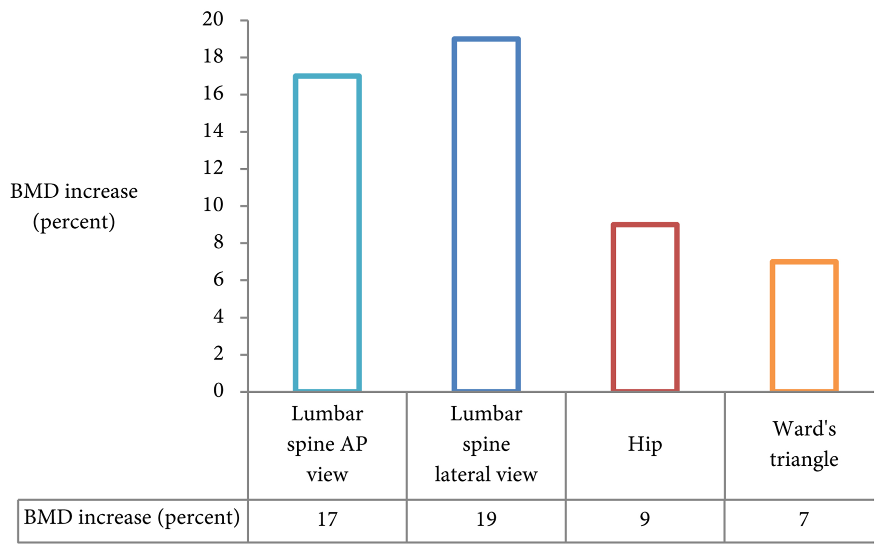


Figure 3. Influence of boxing practice on bone mineral density (BMD) increase. BMD increase varies according to the anatomical region of the skeleton and shows that the mechanical strain resulting from the boxing stance varies according to the skeleton region.

bones [47]. Stronger forces of muscular contraction increase the mechanical stress on bone, and bone must subsequently increase in mass and strength to provide a sufficient support structure for hypertrophied muscles [47]. Thus, an increase in muscle strength or mass may result in a corresponding increase in BMD, or the quantity of mineral deposited in a given area of bone [47]. Because pressure will stimulate the appositional bone growth, increased weight bearing will increase the thickness of the bone and density of the shaft [19].

There exists specificity of load-bearing effect on particular regions of the skeleton: if the body interprets the resulting forces as new or unusual, they will stimulate bone growth in the area receiving the strain [47].

The control of bone mass is localized, and mechanical strain and its effect on bone can be very different from one part of the skeleton to another [19]. That is reflected in differences of percentage increases according to the concerned part of the skeleton, as shown by the results of the study here concerned [45].

Effect of load-bearing is also expressed when the dominant arm is compared with the other arm, as suggested by the results obtained from examination of male veteran tennis players [19]. There has been in the dominant limb: 1) in the forearm and the hand, significantly greater volume and circumference values; 2) in the humerus, the ulna and the radius, greater bone width and mineral content values; as well as 3) in the metacarpal bones, significantly larger length, total area and cortical cross-sectional area values.

That the increased hip BMD can be mediated by longitudinal weight bearing on the skeleton [19], has also been illustrated by the results of one of the studies here concerned [45]: there has been BMD increase in the boxers' hip (9%). The study has also signaled BMD increase in the Ward's triangle (7%) and in the lumbar spine (17%). The increase in the lumbar spine BMD may be explained by the fact that each region of the spine is adapted to its function: lumbar vertebrae are wide and strong because they participate in holding most of the body weight, as well as they provide a steady center of mass during movement [48].

It is worth investigating more the anthropometry of the boxing practitioner four limbs as they are subjected to a particular exertion. In fact, most of the time, the boxer adopts a stance referred to as normal or southpaw. In both kinds of stance, the upper and the lower limbs of the same body side are presented before those of the other side. The boxer weight may be loaded more by one body side than by the other side. When the intention is to discourage or to knock out the opponent, the boxer uses most of the time the rear upper limb but the upper limb more used whatever the intention is the fore limb with the lesser possible energy expense (jab). It is interesting to know how is affected BMD while using more frequently with low energy expense a closed fist and how BMD is affected when less frequently with high energy expense the closed fist is used. Moreover, during his career, at least one boxer has changed his stance from normal to southpaw, or the reverse. There also, BMD may possibly be affected.

2.2.2. Reminder and Advice

1) *Reminder*

In boxers aged 15 - 17 years old, it has been found, due to specific loading on the hand bones, a decreasing rate of synostosis in the distal epiphysis of the forearm and hand bones.

In adult boxers, the bone mineral density (BMD) of the boxers' lumbar spine has been found greater than that of the controls by 17% on the AP view and by 19% on the lateral view. Boxers have also shown an increase in hip BMD up to 9% and an increase in Ward's triangle BMD up to 7%.

2) *Advice*

Analysis of data concerned by the present part of the review suggests the following advice.

Using muscular exercise with the purpose of a boxing-beneficial bone mineral accrual should take into account the existence of boxing-specific exercise, such as practicing shadow boxing while holding weights in the hands or while wearing a backpack that contains weights.

2.3. Nervous System Functions and Boxing Practice

Nervous system 1) is composed of neurons and neuroglia (non-neuronal cells) [40]; 2) is divided anatomically into the central nervous system, consisting of the brain and the spinal cord, and the peripheral nervous system, consisting of 12 pairs of cranial nerves and 31 pairs of spinal nerves, and their associated ganglia [40]; 3) perceives stimuli, processes incoming information and immediately reacts to internal and external changes by stimulating appropriate glands and muscles [3]; and, 4) compared with the endocrine system, while controlling and integrating vital body functions, a) acts immediately (milliseconds instead of seconds to hours) and b) delivers neurotransmitters in discrete paths instead of distributing diffusely hormones through the circulation to a large number of targets [49].

2.3.1. Nervous System Functions

1) *Visual Parameter*

Visual acuity is the degree to which the details and contours of objects are perceived, and it is usually defined in terms of the shortest distance by which two lines can be separated and still be perceived as two lines [50].

If the person being tested can see well the letters of a size that he or she should be able to see at 20 feet, the person is said to have 20/20 vision—that is normal vision [18]. A person with 20/15 visual acuity has better than normal vision while one with 20/100 visual acuity has subnormal vision [50].

No difference in visual acuity (20/20) has been found between non-boxer controls and active asymptomatic amateur boxers [51]. Each of both groups comprised 25 approximately age-matched men. In the boxers, mean number of fights was 39.4 and mean number of spar rounds was 192.5.

The results obtained by Wedrich *et al.* [51] are pertinent as good eyesight as well as visual apparatus soundness is required for competitive boxing practice [36].

However, more relevant results would have been obtained studying possible boxing practice-derived change in visual reaction time than studying possible boxing practice-derived change in normal vision to subnormal or better than normal vision.

As a matter of fact, the clinical method for stating visual acuity utilizes letters that have to be seen by persons. While those letters are non-moving objects and those persons are non-moving subjects, most of boxing practice situations are completely different from the situation of stating visual acuity: it lasts very few times 1) when a legal target where a closed fist may be landed remains uncovered or 2) when the cues that make the boxer expect an attack from his or her opponent remain present.

Nevertheless, when one wishes to knock out an opponent, he or she may land closed fists on the opponent's temple, among other areas. Underneath the temple area lie the occipitotemporal and the occipitoparietal fields of the brain cortex. But lesions in the occipitotemporal or the occipitoparietal association fields may lead to abnormalities of visual processing, for instance to akinetopsia, which makes the patient incapable of perceiving the movement of objects [52].

Hence, a violent closed fist landed to the temple may possibly impede the optimal perception of cues that help the boxer expect an attack from his or her opponent. As visual acuity may contribute to the aforementioned cues perception, visual acuity stating is an essential tool to be used before allowing a subject to begin or to go on participating in competitive boxing.

2) *Auditory Parameter*

Auditory brainstem response (ABR), also known as brainstem auditory evoked potentials (BAEP), is an objective measurement of auditory pathway function from the auditory nerve to the mesencephalon [53]. Electrical activity from the eighth cranial nerve and neurons along the brainstem auditory pathways are recorded by surface electrodes placed on the scalp, forehead, and near the ears for 10 milliseconds after an acoustic stimulus [53]. The readings consist of a sequence of up to 7 positive wave peaks labeled I-VII with negative troughs in-between [53].

Boxing practice has been found to change in professional boxers values of auditory brainstem response I-V inter-peak latency (ABR I-V IPL): there has been shortening of the values after any kind of exertion, either with or without closed fists impact to the head.

In fact, in 18 to 28 years old male professional boxers who received repeated impact to the head and were often concussed, auditory brainstem response (ABR) I-V inter-peak latency (I-V IPL) showed shortened values when between, respectively, pre-exertion group (4.30 ± 0.18 m sec), pre-sparing state (4.24 ± 0.15 m sec), and the state of pre-training without impacts to the head (4.34 ± 0.22 m sec), comparison has been held with post-bout group (4.02 ± 0.15 m sec) ($p < 0.01$), post-sparing state (4.10 ± 0.13 m sec) ($p < 0.01$), and the post-training state without impacts to the head (4.19 ± 0.22 m sec) ($p < 0.01$) [54]. Please see **Table 6** and **Figure 4**. However, no significant difference has been found between the ABR I-V IPL values shown by the knocked-out group (4.04 ± 0.11 m sec) and those shown by the non-knocked-out group (4.01 ± 0.17 m sec). Please see once more **Table 6** and **Figure 4**.

A subsequent study evidenced a correlation between latency changes in ABR and tympanic membrane temperature: the temperature increase by 0.82˚C ± 0.27˚C was accompanied with an ABR I-V IPL shortening from 4.24 ± 0.60 m sec to 4.10 ± 0.11 m sec ($p < 0.01$) [55].

Boxing practice-induced increase in body temperature could thus possibly have contributed to the auditory brainstem response I-V inter-peak latency values shortening.

3) *Perceived Exertion and Perceived Recovery*

a) *Perceived Exertion*

Table 6. Influence of professional boxing practice on values of auditory brainstem response I-V inter-peak latency (ABR I-V IPL) (m sec).

Post-bout group		*Pre-bout group*
4.02 ± 0.15	<	4.30 ± 0.18
Post-sparring state		*Pre-sparring state*
4.10 ± 0.13	<	4.24 ± 0.15
State of post-training without impacts to the head		*State of pre-training without impacts to the head*
4.19 ± 0.22	<	4.34 ± 0.22
Knocked-out group		*Non-knocked-out group*
4.04 ± 0.11	=	4.01 ± 0.17

a. "<" means "are values lower than". b. "=" means "are values not significantly different from". c. Shortening of the values has taken place after any kind of exertion, either with or without closed fists impacts to the head. However, no significant difference has been found between the values shown by the knocked-out group and those shown by the non-knocked-out group. d. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

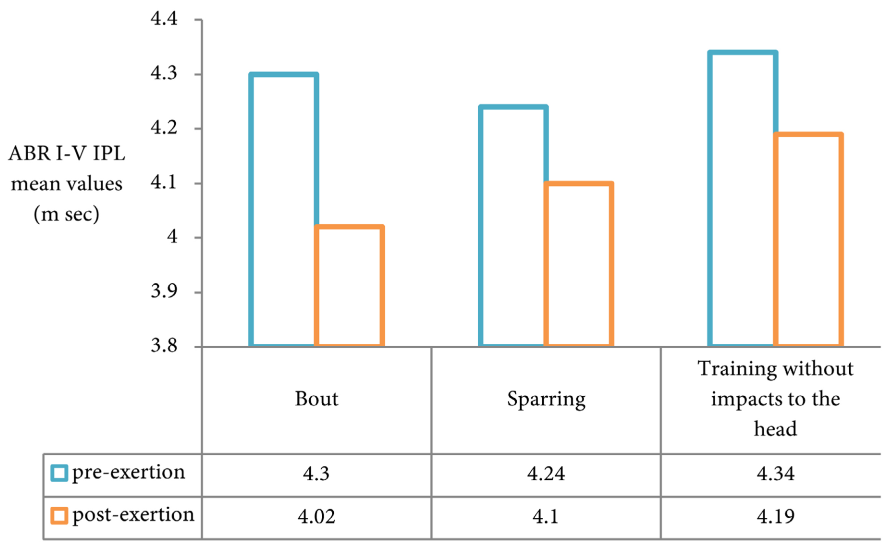


Figure 4. Influence of professional boxing practice on values of auditory brainstem response I-V inter-peak latency (ABR I-V IPL) (m sec). Shortening of the values has taken place after any kind of exertion, either with or without closed fists impacts to the head.

Perceived exertion may be defined as the conception one has of the physical intensity with which one sets his or her body to a defined task, or, more simply, the sensation of a given physical work intensity [56].

Ratings of perceived exertion require that scales be designed and show previously fixed effort levels and that each concerned subject attempts to fit his or her sensations with the concerned scale [56].

Subjects enrolled in a study interested in cardiorespiratory response and fitness boxing have been able to significantly ($p < 0.05$) perceive that they were performing at increasing work levels with each increase in punching tempo [13]. Ratings of perceived exertion (RPE) have been reported by the subjects during recovery between trials. The dependent variable RPE has been related to the independent variable punching tempo. Boxing tempos have ranged from 60 to 120 $b.min^{-1}$, RPE have ranged from 2.3 to 4.2 units, the percentages of oxygen uptake have ranged from 67.9% to 72.3% of maximal oxygen uptake, and the heart rate responses have ranged from 85.6% to 93.1% of maximal heart rate. With increasing boxing tempo, ventilation values have shown a trend to increase. The subjects enrolled in the study were 12 men and 6 women; with 30 hours of fitness boxing experience; of (mean ± SD) age 22.0 ± 2.8 years, height 170.8 ± 7.7 cm, body mass 71.5 ± 12.6 kg, RPE max 18.6 ± 0.8 units; who completed 6 two-minute randomized fitness boxing trials at increasing tempos, while wearing 0.34-kg boxing gloves.

It has not been possible to reach a general agreement or a unifying theory on physiological variables that help a subject perceive exertion [56]. However, people have agreed that ratings of perceived exertion procedure is easy to use, cheap, accessible to practically all the levels, reliable and useful [56].

In the study here concerned [13], expectable heart rate and ventilation trial responses that accompanied rating of perceived exertion (RPE) trial have proven the RPE to be a reliable procedure: 1) some exceptions apart, in many types of exercise, the increase in heart rate is linear with the increase in rate of exercise [19]; what is consistent with the concomitant increase of both heart rate and RPE values with increasing punching tempo; and 2) during resistance exercise, ventilation is significantly elevated during each set [47]; what is consistent with the concomitant increase of both ventilation and RPE values with increasing punching tempo.

Attention must be drawn to the fact that an increase in oxygen uptake was not to be expected with increasing punching tempo. In fact, while during exercise the heart rate increases linearly with the oxygen uptake for the average person [19], towards total energy expenditure, boxing practice rely more on anaerobic processes (up to a 70 percent [4]) than on aerobic processes.

b) *Perceived Recovery*

Recovery is the process of returning from the post-exertion state to the pre-exertion state. After a sporting session, recuperation is aimed at restoration of the initial potentials [57]. Perceived recovery after a sporting session may thus be defined as the conception one has of his or her body having returned to its pre-exertion state.

One of the aims of a study has been to investigate the effects of massage on perceived recovery and blood lactate removal [58]. Of (mean ± SD) age 24.9 ± 3.8 and height 1.8 ± 0.07 m, the 8 male amateur boxers enrolled in the study have been able to perceive recovery that correlated positively and significantly with blood lactate response ($r = 0.50$, $p < 0.05$).

Some could have expected a negative correlation to link perceived recovery and blood lactate [58], what is not consistent with the results published by the authors of the study here concerned [58].

On the one hand, the muscular fatigue experienced during exercise often correlates with high tissue concentrations of lactate [59]. On the other hand, protons (H^+) may be involved in both peripheral and central fatigue [38]. In the peripheral fatigue, the impairment is located in the muscle, while in the central fatigue, the impairment is located in the central nervous system, including the α-motor neuron in the spinal cord [38].

Protons may derive from the lactate dehydrogenase reaction which yields, from pyruvate, simultaneously one proton and one lactate ion [59]. However, other mechanisms, such as the hydrolysis of adenosine triphosphate (ATP), have been suggested to yield most of the protons accumulation and lactate to be used in gluconeogenesis during extended exercise and recovery [59].

Measurement of blood lactate, what has been carried out by the authors of the study here commented, could thus help estimate only the amount of protons that derive from the lactate dehydrogenase reaction, leaving out of account the protons that are yielded by other mechanisms. Moreover, protons are not the unique fatiguing agent during exercise. Ammonia, for instance, has been mentioned: although direct evidence for plasma ammonia as a fatiguing agent during exercise is weak, it has been suggested that increased plasma levels of ammonia could impair central nervous system function and contribute to fatigue [38].

4) *Enhancement of Biceps Brachii Muscle Mechanical Power Induced by Vibrations during Elbow Flexion*

The junction between a motor neuron and the muscle fibers it innervates is called the motor end plate, or more often, the neuromuscular junction [60]. In the intact human, healthy skeletal muscle does not contract except in response to stimulation of its motor nerve supply [50]. When a motor neuron fires an impulse or action potential, all of fibers that it serves are simultaneously activated and develop force [60].

In a motor neuron, the action potential, electrical information, is transduced to a chemical signal in the form of a neurotransmitter, acetylcholine (Ach), which is transduced back to an action potential in the muscle [61]. The action potential in the muscle is then transduced to mechanical work as a muscle twitch [61].

Theoretically, speaking of a motor neuron, increased neural activation may result from events that take place from the beginning of a reflex, for instance the reflex elicited through vibration, to the release of acetylcholine into the synaptic cleft by the concerned motor neuron. Any increase in the excitatory drive, any decrease in the inhibitory influence or both things may be expected to increase the motor neuron firing rate, with the resulting increased motor neuron activation.

Theoretically, increased neuromuscular efficiency may result from events that take place from acetylcholine release into the synaptic cleft by the concerned motor neuron through acetylcholine transduction to mechanical work as a muscle twitch [61]. Increasing the availability of acetylcholine in the synaptic cleft may increase neuromuscular transmission [52]. Thus, increased neuromuscular efficiency is increased success in transmission of the nerve signals from the motor neuron to the muscle fibers, for instance, a shortened time that elapses between acetylcholine release and the muscle twitch.

Greater neural activation may be indicated by an increase in electromyography (EMG), a common research tool used to determine the magnitude of neural activation following training [47].

As efficiency is the quality of doing something well and in a way that produces the result that was intended [2], neuromuscular efficiency improvement may be seen when, a neuromuscular junction functioning, either 1) for the same neural activation (EMG), the innervated skeletal muscle shows an increase in power (P); 2) for a lesser neural activation (EMG), the innervated skeletal muscle shows the same power (P); or 3) for a lesser neural activation (EMG), the innervated skeletal muscle shows an increase in power (P).

Increases in *biceps brachii* muscle mechanical power, in neural activation and in neuromuscular efficiency have been found in a study that has been undertaken with the aim of evaluating the influence of vibration on the mechanical properties of arm flexors. The study had enrolled 12 active international level boxers, all members of the Italian national team. From the results obtained, the authors pointed out 1) a significant enhancement ($p < 0.001$) of the neural activity during vibration treatment of *biceps brachii* muscle and 2) an improvement of neuromuscular efficiency of the elbow flexors [62].

Neural activity enhancement was shown by vibration-induced increase ($p < 0.001$) in electromyogram root-mean-square (EMGrms) values during vibration treatment when compared with pre-vibration values, while there has been no significant difference when comparing the pre-vibration values with the post-vibration values.

Neuromuscular efficiency improvement was shown by the association of vibration-induced average power (P) increase ($p < 0.001$) with a decrease ($p < 0.01$) of the related EMG/P relationship.

5) *Verbal Learning*

Something verbal may be seen as something spoken rather than written [2]. Something verbal may also be seen in something relating to words or using words [2]. Spoken or written, verbal learning always relates to words.

Learning is a process whereby information is acquired, what makes possible a behavior change on the basis of experience [50].

Storage of the information is referred to as memory [18]. However, what is remembered is also referred to as memory [2].

One can safely assume that verbal learning includes 1) information acquisition through hearing words or seeing words [61], 2) committing the new information from short-term to long-term memory [18] [50] [61], and 3) information storage [18] [61], what makes possible 1) recalling of the information as it is needed

[18], 2) recognizing different words [18], 3) recognizing the thoughts that are conveyed by those words [18], 4) arranging those words into a coherent thought [18], and 5) saying words or writing words [61].

Most of individuals are right-handed and in most of them, the left (categorical) cerebral hemisphere deals with language, that is, understanding the spoken and written word, and expressing ideas in speech and writing [50].

According to a British Medical Association (BMA) report, boxing practice may be responsible for structural damage to the brain [63]. Meanwhile, 1) a possible way to achieve an early boxing victory is to land hard closed fists on vital areas, and 2) most of the latters are situated at the opponent's head, in which is situated the brain.

Because 1) in most individuals, the left cerebral hemisphere deals with language [50]; 2) most boxers are right-handed and thus land with their rear closed fist hooks on their opponents left temples; 3) maximal forces are larger for the rear than for the lead hand [64]; and 4) hook punch force is greater than those of uppercut and straight punches [65]; a damage to the left (categorical) cerebral hemisphere may be expected from the hard hit (hook) when it is landed on one's opponent's temple (vital area). That may result in trouble understanding written language [50] and difficulties to read accurately and fluently [50].

A closed fist attack could possibly result in the superior temporal gyrus damage. In that case, the damage could be expected to interfere with normal processing of auditory inputs [61].

In the case that the boxing attack damages the angular gyrus in the categorical cerebral hemisphere, there could be trouble understanding written language [50] by the attacked boxer who may also be unable to interpret the meanings of the words [18].

A boxing attack that damages a boxer's Wernicke's area may possibly make the victim unable both to arrange the words heard into a coherent thought and to recognize the thought that is conveyed by the words read [18].

Boxing practice may thus be responsible of verbal learning impairment. That is consistent with one of the conclusions drawn by a research team: boxers showed less proficiency while verbal learning, compared to control non boxing subjects [66].

Attention of research workers has also been drawn to the possibility of cognitive test performance deterioration in the immediate post bout period [67]. The concerned study utilized 30 matched non boxing control subjects and 82 collegiate amateur boxers in a 7-day amateur boxing tournament. The boxers participated in one, two or three bouts.

With the exception of boxers whose contest has been stopped by the referee, the boxers displayed no evidence of cognitive dysfunction in the immediate post-bout period. Moreover, an improvement in performance was observed on the administered learning task in boxers who participated in each of the three bouts.

Hence, the small proficiency shown by boxers while verbal learning [66], or while learning in general, could possibly be a cumulative process.

6) *Reaction Time*

Reaction time is the time it takes from the detection of a stimulus to the first movement [68].

Speed which, in mechanical terms refers to the time taken to complete a linear or angular distance, is the result of reaction speed (reaction time) and movement speed [68].

As evidenced by quicker values shown by elite compared to novice sprinters, reaction time can be improved through signal recognition and efficient execution of movement patterns [68].

The possible improvement is also supported by the faster reaction time shown by young subjects trained to boxing than the one shown by matched control subjects in a prospective investigation of neurobehavioral functioning [66].

However, it is worth signaling that reaction time has been said relatively un-trainable and correlating poorly with movement action time or performance in many explosive events [69].

Other results worth signaling are significant slowing in simple reaction time and choice reaction time in boxers whose bouts have been stopped by the referee [67]. The concerned study had enrolled in a 7-day amateur boxing tournament 30 matched non boxing controls and 82 collegiate amateur boxers. The latters participated in one, two or three bouts.

7) *Conative Regulators and Cognitive Processors*

a) Conative Regulators

Is conative what is connected with the mental process that makes one want to do something or decide to do something [70]. A regulator is someone who makes sure that a system operates properly or fairly [2]. A conative regulator may thus be seen for instance, 1) in any neural activity that makes one interrupt an intended boxing-specific attack when one thinks that the probability of occurrence of a preventive attack from the concerned opponent is high, and 2) in any neural activity that makes one think that circumstances are sufficiently safe for one to perform a boxing attack without being counter-punched by the concerned opponent.

To strike is to deliberately hit someone or something with one's hand or a weapon [2]. Efficiency is the quality of doing something well and in a way that produces the result that was intended [2]. Perceived hand-striking efficiency is thus the conception one has of expecting the intended result when one's closed fist has been landed on a concerned opponent legal target.

Perceiving hand-striking as inefficient could constitute a conative variable with negative impact on the appearance of boxing attack techniques (straights, uppercuts and hooks) within a particular period of time.

It has been signaled [36] that performance of boxing attack techniques varies according to the distance that lies between the closed fists of the attacking boxer and the legal targets that are situated on the attacked boxer's physical structure: there exist distances where may be performed either all, some or even no kind of boxing attack techniques.

According to the distance, the boxer may thus perceive one's personal hand-striking as efficient or inefficient, what makes the perception a conative variable with positive or negative impact, respectively.

That is consistent with the conclusion that has been drawn from a study that was interested in the effects of participant-target distance and perceived hand-striking efficiency on emergent behavior in boxing: the probability of occurrence of jabs, hooks and uppercuts depends on boxer-perceived hand-striking efficiency which in turn depends on scaled boxer-target distance [71]. The concerned results established that there exist critical values of scaled distances for the emergence of first time excitations and annihilations of a range of boxing actions, i.e. the appearance of jabs, hooks and uppercuts.

According to the law of effect, a behavior that elicits reward is repeated, while the behavior that elicits punishment is not repeated [61]. Efficiency of response learning (here, repetition or non-repetition) will be stronger, the shorter the time that is allowed to elapse between the behavior and the reward or the noxious outcome [61].

During pugilistic work, athletes box with the aims of 1) not being touched by the opponent and 2) touching the opponent without hurting the latter (in educational boxing [72] [73]) or 3) hitting hard the opponent (especially in professional boxing).

A behavior may be dictated by the activation of one or the other among the three systems of primitive emotions 1) the behavioral inhibition system (BIS), 2) the behavioral activation system (BAS) and 3) the fight or flight system [74]). Each of the three systems is composed of nervous anatomical structures [74] whose physiological manifestation may constitute conative variables with a) negative impact when BIS or flight are concerned or b) positive impact when BAS or fight are concerned.

Almost everything that one does is related in some way to reward and punishment: if one is doing something that is rewarding, one continues to do it; if it is punishing, one ceases to do it [18].

Possible conative regulators with negative impact while boxing are 1) suffering a hard hit from an opponent, 2) performing unsuccessfully a boxing technique of either attack or defense, 3) being ridiculed by one's opponent during the boxing match, … Possible conative regulators with positive impact that may take place when one is boxing are: a) the thirst for winning the opponent, b) the thirst for performing successfully a boxing technique of either attack or defense, c) money to be earned for the boxing match, …

Below, activation of BIS is illustrated by what has been referred to as "the ¡No más! battle", while BAS activation is illustrated by 1) the behavior of Muhammad Ali and Joe Frazier during their third and last battle, and 2) the behavior of the boxers during the longest match of boxing history.

The "¡No Más! Battle"

On November 25, 1980 Ray Sugar Leonard had been out-boxing him and making a fool of him, when having had enough of that, two minutes and 44 seconds into the eighth round of his welter-weight title defense, Roberto Durán took the decision to simply turn away from Leonard towards the referee so as to quit the fight by apparently saying "¡No más!" (No more!) [75] [76].

Muhammad Ali vs. Joe Frazier III

On March 8, 1971 at Madison Square Garden, Joe Frazier wins Muhammad Ali. On January 28, 1974 at Madison Square Garden, Ali takes revenge for his loss: Frazier is defeated by Ali. On October 1, 1975 in Manilla takes place the third and last battle between the two boxers. Next year, in a book, Muhammad Ali and Richard Durham tell the following [36]. At the sixth round, Ali is deeply affected by the punches Frazier has thrown to Ali's body. Exhausted before the middle of the battle, Ali wonders whether he is going to be able to finish the battle begun. He knows that Frazier will never abandon. Frazier's face has turned into a mass of cuts and bumps. His eyes are closed. At the ninth round, pain suffered by Ali is almost unbearable. At the tenth round, for the first time on a ring, Ali experiences the feeling that he is on the verge of death, of his death, and from then the least punch he throws brings him closer to the grave. In spite of all that, he goes on pushing, beating, killing himself. As for Frazier, he all the time mounts fresh attacks. He refuses to fall down. Ali wonders what then drove both of him and Frazier.

They were possibly driven to such behaviors by activation of their respective BASs.

The Longest Boxing Match in History

On April 6, 1893 at the Olympic Club in New Orleans (Louisiana, USA) Andy Bowen and Jack Burke were the contenders for the title of lightweight champion of the South [77] and the prize to be awarded worth $2500 in 1893. The battle took a time so long that, apart from the bruises on each of the fighters, both the latters had their hands broken [77] and, as they became too dazed and too tired to come out of the corners [78], the referee who had had enough, called the match a draw [77]. The fight had then lasted 110 rounds over 7 hours and 19 minutes [36], each round lasting three minutes [78]. Each of the contenders has been rewarded $1250 [77].

Such dogged determination may possibly have benefited from BASs activation of the two boxers

b) *Cognitive Processors*

Is cognitive, what is related to the process of knowing, understanding and learning something [2]. A processor is the central part of a computer that deals with the commands and information it is given [2]. A cognitive processor may thus be seen in any nervous system part that deals with afferent information so as to allow knowing, understanding and learning the concerned information.

The cognitive process of learning may thus help the boxer improve his abilities so as to be more successful while performing 1) defense techniques, 2) attack techniques and 3) simultaneous defensive and attacking techniques. That cognitive process of learning may thus possibly have a positive impact upon boxing techniques performance while decreasing the negative impact of conative processes that could have prevented performance of the aforementioned techniques.

All aforementioned is consistent with the results yielded by a study aimed to analyze the relationship that exists between cognitive processors and conative regulators with specific motor abilities of elite boxers [79], study which revealed 1) a predominant impact of serial processor on specific motor abilities based primarily on specific speed (frequency of boxing technique performance) and 2) a predominant negative impact of dis-regulation of the organ function regulators from the set of conative variables on the manifestation of specific motor abilities in boxers.

2.3.2. Reminder and Advices

1) *Reminder*

No difference in visual acuity (20/20) has been found between non-boxer controls and active asymptomatic amateur boxers.

Boxing practice has been found to change in professional boxers values of auditory brainstem response I-V inter-peak latency (ABR I-V IPL): there has been shortening of the values after any kind of exertion, either with or without closed fists impact to the head. A subsequent study evidenced a correlation between ABR I-V IPL shortening and tympanic membrane temperature increase.

During fitness trials, subjects have been able to significantly perceive that they were performing at increasing work levels with each increase in punching tempo.

Male amateur boxers have been able to perceive recovery that correlated positively and significantly with blood lactate response.

In active international level boxers, it has been pointed out vibration-induced 1) increase in *biceps brachii* muscle mechanical power, 2) enhancement of the neural activity during vibration treatment of *biceps brachii* muscle, and 3) improvement of neuromuscular efficiency of the elbow flexors.

Boxers have shown less proficiency while verbal learning, compared to control non boxing subjects.

With the exception of boxers whose contest has been stopped by the referee, boxers have displayed no evidence of cognitive dysfunction in the immediate post-bout period. Moreover, an improvement in performance has been observed on the administered learning task in those of the boxers who participated in each of the three bouts to which they have been subjected.

Reaction time has been faster in young subjects trained to boxing than in matched control subjects.

Slowing in simple reaction time and choice reaction time has been suffered by boxers whose bouts have been stopped by the referee.

The probability of occurrence of jabs, hooks and uppercuts has been found to depend on boxer-perceived hand-striking efficiency which, in turn, depends on scaled boxer-target distance.

It has been revealed 1) a predominant impact of serial processor on specific motor abilities based primarily on specific speed (frequency of boxing technique performance) and 2) a predominant negative impact of dis-regulation of the organ function regulators from the set of conative variables on the manifestation of specific motor abilities in boxers.

2) *Advices*

Analysis of data concerned by the present part of the review suggests the following advices.

Studies should better deal with possible boxing practice-derived change in visual reaction time. Visual acuity stating should be one of the tools to be used before allowing a subject to begin or to go on participating in competitive boxing.

Auditory brainstem response studies in boxers should be completed with studies interested in electrical activity taking place in auditory pathways situated next to the mesencephalon to auditory cortices and from there to the descending auditory pathways. The result could also be used as one of the tools to be used before allowing a person to begin or to go on practicing boxing.

Studies should be undertaken to find out what is the most beneficial to the boxer, speaking of neuromuscular efficiency vibration-influenced or the same efficiency boxing exercise-influenced.

Boxers should train to perform successfully boxing techniques of either defense, attack or simultaneous defense and attack. They should also train their thirst for winning the opponent as well as for performing successfully the aforementioned boxing techniques.

At the beginning of each round, the boxer should better scale the distance that is going to permit him to land with efficiency his closed fists on the legal targets that are situated on his opponent's organism.

If deficit in material justifies it, research workers may have confidence in the use of ratings of perceived exertion as well as in the use of ratings of perceived recovery, where applicable.

2.4. Endocrine System Functions and Boxing Practice

Endocrine system consists of gland cells and neurons both producers of chemical messengers referred to as hormones [49], messengers which 1) are secreted into the extracellular fluid ("internal sea") [33], 2) contribute to control and integration of vital body functions [49], and 3) compared with the neurotransmitters, a) act over longer periods of time (seconds to hours instead of milliseconds) and b) often are distributed diffusely to a large number of targets [49], instead of having discrete paths of delivery.

As far as boxing practice is concerned, data that have been collected deal with 1) pituitary volume, 2) two pituitary hormones (adrenocorticotropic hormone and growth hormone), 3) a growth hormone intermediate (insulin-like growth factor-1), as well as a non-pituitary hormone (erythropoietin).

2.4.1. Glands, Hormones and Hormone Intermediate

1) *Pituitary Volume*

Retired boxers with growth hormone (GH) deficiency have shown significantly lower pituitary volume than retired boxers with normal GH [80], as shown in **Table 7**.

Table 7. Influence of boxing practice on endocrine system variables.

	Pituitary volume in retired boxers, relative to growth hormone (GH) values	
volume in boxers GH deficient	<	volume in boxers with normal GH
	Adrenocorticotropic hormone (ACTH) deficiency rate in retired or active amateur male boxers	
	8%	
	Growth hormone (GH)	
	Mean peak GH levels	
boxers		non-boxing controls
$10.9 \pm 1.7\ \mu g \cdot l^{-1}$		$41.4 \pm \mu g \cdot l^{-1}$
	Negative correlations	
increasing boxing duration	↔	decreasing peak GH levels
increasing number of bouts	↔	decreasing peak GH levels
	GH deficiency rates	
both active and retired boxers	active boxers	retired boxers
15% of all the boxers	1.6% of all the boxers	13% of all the boxers, but 47% of the retired boxers
	Insulin-like growth factor-1 (IGF-1) mean levels	
boxers		controls
$237 \pm 23.3\ ng \cdot dl^{-1}$		$367 \pm 18.8\ ng \cdot ml^{-1}$
	Erythropoietin (EPO) values in non-iron-depleted boxers, post-training at moderate altitude (1800 m)	
values increase in iron-treated boxers	=	values increase in placebo-treated boxers

a. “<” means “is lower than”. b. “↔” means “correlates with”. c. “=” means “is present in both samples”. d. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

It is not unsound to expect the decrease of an organ volume with the decrease of its use or of its stimulation.

Retirement from boxing practice could have contributed to the decrease in pituitary volume shown by retired boxers when compared with actively competing boxers, as the retirement results in 1) the decrease in intense exercise performance, 2) the decrease in boxing practice-derived stress, and 3) the decrease in epinephrine stimulation of pituitary.

Furthermore, anterior pituitary gland may possibly experience temporary enlargement, as is the case during pregnancy [18]. Maybe such enlargement occurs in actively competing boxers and disappears with boxing practice retirement, what could contribute to the pituitary volume significantly lower in retired boxers than in actively competing boxers.

The authors of the study confess that no comparison group has been investigated. More meaningful results than the ones published could have been obtained 1) comparing each boxer with sedentary not boxing controls and 2) using each boxer also as his own control at various moments: a) before his competition debut, b) during his competition period, and c) at his retirement debut.

2) *Adrenocorticotropic Hormone*

Adrenocorticotropic hormone (ACTH, adrenocorticotropin, corticotropin) is a hormone secreted by the pituitary anterior lobe (adenohypophysis), a gland which is located beneath the hypothalamus [49] [61]. Non-glandular sources of ACTH are the macrophages, monocytes, lymphocytes which are located in the blood [49]. ACTH stimulates the production of glucocorticoids and androgens by the adrenal cortex [18].

A study has had the objective of investigating the pituitary function in retired or active amateur male boxers of the Turkish National Boxing Team. The study threw up, among other results, what follows: 1) 8% of the boxers suffered ACTH deficiency, what signals **Table 7**, 2) 15% of all the boxers suffered GH deficiency, 3) GH deficiency was shown by one active boxer (1.6% of all the boxers) as well as by retired boxers (13% of all the boxers but 47% of the retired boxers), and 4) retired boxers with GH deficiency had lower pituitary volume than retired boxers with normal GH values [80].

What may be the causes of ACTH deficiency?

It is known that hypothalamic corticotropin-releasing factor (CRF) stimulates release of ACTH from the anterior pituitary gland, and ACTH, in turn, stimulates cortisol secretion from the adrenal cortex [49]. Cortisol also stimulates biosynthesis of epinephrine in the adrenal cortex and epinephrine stimulates ACTH secretion from the anterior pituitary gland [49]. Boxing has been classified among sports that cause severe energy expenditure (46 - 60 $kJ \cdot min^{-1}$) [4]. Meanwhile, during excessive physical effort, feedback regulation of CRF and ACTH by cortisol is impaired [49]. That makes expect, from pugilistic activity, high rates of ACTH. Additionally, chronically high norepinephrine and cortisol titers can produce neuronal damage and memory loss [49]. Pugilistic activity could possibly have produced high titers of those hormones and the consequent damage to the neurons responsible for ACTH secretion in the boxers here concerned.

As CRF stimulates ACTH release which, in turn, stimulates cortisol secretion [49], a decrease in ACTH values may result from 1) impaired function of the hypothalamus and/or the pituitary gland, which fail to produce sufficient CRF and/or ACTH respectively; 2) reduced number of CRF- and/or ACTH-producing cells; insufficient stimulation of CRF- and/or ACTH-producing cells; and 4) accelerated degradation and/or excretion of CRF and/or ACTH; among others.

Retired boxers of the study with GH deficiency have shown significantly lower pituitary volume than retired boxers with normal GH values [80]. That could make expect decreased values of all the hormones (ACTH included) produced and secreted by the anterior pituitary gland or even by the whole pituitary gland. In the case of only the hormones of the anterior pituitary gland, the situation would be near to panhypopituitarism (the decreased secretion of all the anterior pituitary hormones [18]). In the case of the hormones of the whole pituitary gland, it is not unsound to expect the additional decrease of posterior pituitary gland. But no decrease in antidiuretic hormone (ADH) has been found in boxers showing a decrease in mean peak GH levels [81]. Whatever which of both cases, the situation could possibly result from head trauma due to boxing practice with consequent damage to hypothalamus or to pituitary gland. In fact, damage to hypothalamus or to pituitary gland may result in ACTH secretion decrease [52].

Tanriverdi *et al.* confess that there has not been any comparison between boxers and non-boxing persons in the study that evidenced ACTH deficiency in boxers [80]. More meaningful results could have resulted from comparison between active and retired boxers. It could also have been worth comparing on each boxer ACTH secretion before, during and after his pugilistic career.

3) *Growth Hormone*

Growth hormone (GH, somatotropic hormone, somatotropin) is a hormone secreted by the pituitary anterior lobe (adenohypophysis), a gland which is located beneath the hypothalamus [49] [61]. The non-glandular source of GH variants is the placenta which is located in the uterus [49]. In the adult, GH targets a number of tissues to stimulate muscle protein synthesis, bone elongation, and lipolysis [61]. GH causes growth of almost all tissues of the body that are capable of growing [18].

Pituitary function has been investigated in retired or still actively competing male boxers [80] [81]. Two studies that have carried out that duty have been here examined.

One of the studies compared hormones values shown by non-boxing controls with those shown by the boxers [81]. Some of the results obtained were as follows: 1) mean peak GH levels were significantly lower ($p < 0.05$) in boxers (10.9 ± 1.7 μg·l^{-1}) than in non-boxing controls (41.4 ± 6.7μg·l^{-1}), what signals **Table 7**, 2) mean IGF-1 levels were significantly lower ($p < 0.01$) in boxers

(237 ± 23.3 ng·dl^{-1}) than in non-boxing controls group (367 ± 18.8 ng·ml^{-1}), and 3) a negative correlation linked peak GH levels with boxing duration as well as peak GH levels with number of bouts, what also signals **Table 7**.

Without comparing non-boxing controls values against boxers values, the other study evidenced GH deficiencies in boxers: 1) 15% of all the boxers enrolled suffered GH deficiency, 2) GH deficiency was shown by active boxers (1.6% of all the boxers) as well as by retired boxers (13% of all the boxers but 47% of the retired boxers) and 3) retired boxers with GH deficiency had lower pituitary volume than retired boxers with normal GH values [80]. Please see **Table 7**.

Effect of GH

GH exerts much of its effect through intermediate substances called "somatomedins" or insulin-like growth factors [18] (IGF, e.g., IGF-1). However, GH and IGF-1 could act both in cooperation and independently to stimulate pathways that lead to growth [50] of almost all tissues of the body that are capable of growing [18]. That could explain why, compared to the values shown by non-boxing controls, the values shown by the boxers were lower, concerning not only mean peak GH levels, but also mean IGF-1 levels [81].

In response to GH stimulation, among other intermediate substances, the liver synthesizes IGF-1 [33]. GH promotes the formation of erythropoietin (EPO), in part through the mediation of hepatic somatomedins or insulin-like growth factors (IGF, e.g., IGF-1) [52].

Regulation of GH Secretion

The stimuli of GH secretion can act by increasing hypothalamic secretion of growth hormone-releasing hormone (GHRH), by decreasing hypothalamic secretion of growth hormone-inhibiting hormone (GHIH, somatostatin, SS), or both [50]. IGF-1, from liver and other tissues, inhibits GH secretion either directly or through stimulation of SS secretion [50].

Deficiency of GH Secretion

Among other causes, GH deficiency may be due to decreased hypothalamic stimulation, inhibition of release or damage of the hormone-producing cells [52].

Decreased Hypothalamic Stimulation of GH Secretion

The decline in spontaneous GH secretion is exponential after adolescence [49].

That seems to be reflected in the results yielded by the two studies here examined: 1) a negative correlation has appeared between peak GH levels and boxing duration as well as between peak GH levels and number of bouts [81]; and 2) GH deficient boxers of one study were comprised of 89% of retired boxers versus 11% of actively competing boxers [80]. In fact, it is expected that 1) boxers concerned with the two studies were older than adolescents; 2) generally, with increasing age, there are increases in a) boxing duration as well as b) number of bouts; and 3) generally, retired boxers are older than, have had more dur-able career than and have fought more bouts than still actively competing boxers.

Inhibition of GH Release

The decline in spontaneous GH secretion is believed to be caused both by atrophy of some growth hormone-releasing hormone (GHRH) neurons as well as by increased brain somatostatin action [49].

Could boxing practice-derived GH secretion decline result from one of or from both causes? Nevertheless, changes in physiological or non-physiological demands may result in cells aplasia or cells atrophy as hormonal adaptation [52]. It is as if a GH decrease is necessary either for an optimal pugilistic practice or for preventing pathophysiological changes incompatible with boxing practice.

Damage of GH-producing Cells

On the one hand, boxing may result in traumatic brain injury, and on the other hand, traumatic brain injury is known as a cause of hypopituitarism [81]. The term pan-hypopituitarism refers to the decreased secretion of all the anterior pituitary hormones [18].

A situation near to pan-hypopituitarism is suggested by the results of the two studies here examined. Violent blows to the head may possibly have damaged the hypothalamus and/or pituitary gland cells in the boxers. The consequence may have been 1) mean peak GH levels higher in non-boxing controls than in boxers [81], 2) a negative correlation linking peak GH levels with boxing duration as well as with number of bouts [81], 3) percentage of GH deficiencies lower in active than in retired boxers [80], and 4) pituitary volume lower in GH deficient retired boxers than in retired boxers with normal GH values [80].

The aforementioned violent blows could have affected only the anterior but not the posterior pituitary cells. As a matter of fact, there have been neither change in antidiuretic hormone (ADH) values, nor signs and symptoms of diabetes insipidus [81], while there have been GH deficiencies [80] [81] and deficiencies of adrenocorticotropic hormone (ACTH) [80]. Here appears the need to investigate the possible contribution of violent blows-induced damage of GH-producing cells versus the possible contribution of hormonal adaptation to demands of boxing practice and to demands of boxing retirement.

4) *Insulin-Like Growth Factor*-1

Growth hormone (GH) exerts much of its effect through insulin-like growth factors (IGF), IGF-1 being by far the most important of those factors [18].

IGF-1 is synthesized by the liver and skeletal muscle. It is one of the substances responsible for cell differentiation and tissue growth [33]. The action of IGF-1 is independent of GH [33].

However, GH increases circulating IGF-1 [50] and, in turn, IGF-1 exerts an inhibitory action on pituitary GH secretion [33] [50], as well as through stimulation of the secretion of somatostatin, which inhibits GH release [50].

Hence, IGF-1 lower values shown by boxers when compared with non-boxing persons may be due to decreased GH values in the formers, compared to the latters, as shown by results from Kelestimur *et al.* [81]: 1) mean peak GH level in boxers and in controls have been 10.9 ± 1.7 and 41.4 ± 6.7 $\mu g \cdot l^{-1}$, respectively ($p < 0.05$), while 2) in the control group, mean IGF-1 levels (367 ± 18.8 $ng \cdot ml^{-1}$) have been higher than those obtained in boxers (237 ± 23.3 $ng \cdot dl^{-1}$) ($p < 0.01$). Please see **Table 7**.

5) Erythropoietin

Erythropoietin (EPO) is a circulatory hormone, principal stimulus for red blood cell production in low oxygen states [18].

EPO production stimuli comprise epinephrine, norepinephrine and several prostaglandins [18], as well as growth hormone, partly through the mediation of hepatic somatomedins, e.g., IGF-1 [52].

EPO secretion stimuli are comprised of hypoxia [19] [50] in the kidney and other parts of the body [18], alkalosis that develops at high altitudes [50], androgens [19] [50], thyroid hormones [triiodothyronine (T_3) and thyroxine (T_4)] via increased oxygen consumption [52], catecholamines [50], as well as cobalt salts [50].

EPO plasmatic concentration may vary due to exercise, training and altitude [33].

A study has been carried out to test the hypothesis that iron supplementation in well-trained non-iron-depleted boxers leads to an enhanced increase of total body hemoglobin during endurance training at moderate altitude (1800 m) [24]. Among other results yielded by the study, there was a significant increase in EPO in venous blood of both iron- and placebo-treated boxers.

Increase in total body hemoglobin was not to be expected from oral iron supplementation in non-iron-depleted subjects. In fact, after oral administration to the iron-depleted patients, excess iron is lost with the stools [22].

Increase in EPO could be expected from the moderate altitude of 1800 m as 1) when altitude increases from 0 to 2000 m or higher, there occurs a barometric pressure decrease, an inspiratory oxygen partial pressure (pO_2) decrease, and an alveolar pO_2 decrease which causes an arterial pO_2 decrease [74], and 2) hypoxia is a stimulus of EPO secretion [18] [19] [50].

Comparing values reported by various studies on sportspersons, Poortmans [33] felt that hypoxia could not be so an efficient stimulus as to affect EPO rates during a well-tolerated exercise at altitudes lower than 2500 m: on cyclists, one study did not find any increase in basal EPO concentrations; on marathon runners, one study found no increase while another one found that the rates increased by a 10%; meanwhile the study here commented [33] reported that boxers basal EPO concentrations increased by a 30%.

It could be worth signaling that the relatively higher increase in boxers basal EPO concentrations could be due to the fact that towards total energy expenditure, practice rely more on anaerobic than on aerobic processes possibly at a higher degree in boxing than in marathon and long-lasting cycling. The result of that could be a better tolerance of endurance training by cyclists and marathon runners than by boxers, with the consequent higher increase of EPO basal concentration values in the latters than in the two formers sports practitioners.

In fact, with increasing exercise duration of maximal efforts, contribution of anaerobic processes to energy output decreases [10] [19].

The intermittent high energy exercise referred to as boxing is comprised, while competing, of up to 12 rounds lasting each up to three minutes.

In the exercise named cycling, races range from 200 m sprint lasting approximately 10 s to the Tour de France of 23 days covering approximately 5000 km [30].

The races of marathon, a prolonged exercise, are held on road courses over a distance which, for historical reasons, has been fixed as 42,195 m [7]. Elite competitors complete the marathon in times of less than 2 h 10 min whereas many of the slowest runners take more than 5 h to reach the finish [7].

Maximal oxygen uptake ($\dot{V}O_2max$) values have been reported as 65 ml·kg^{-1}·min^{-1} in elite male boxers [4], 67.6 - 77.4 ml·kg^{-1}·min^{-1} in elite male cyclists [30] and 78 - 80 ml·kg^{-1}·min^{-1} in successful marathon runners [7].

What mentioned above suggests that sport practice rely at a lower degree on aerobic processes in boxers than in cyclists and in the latters than in marathon runners. Endurance training could thus overtax more the boxers than the cyclists and the latters than the marathon runners, what would have as results higher basal EPO concentrations in boxers than in cyclists and in the latters than in marathon runners. It should be reminded here that, of the two studies mentioned by Poortmans [33] about marathon runners, one signaled no increase while the other signaled an increase by a 10% of basal EPO concentrations.

2.4.2. Reminder and Advice

1) *Reminder*

ACTH deficiency has been shown by 8% of a sample of amateur male boxers.

A negative correlation has appeared between peak GH levels and boxing duration as well as between peak GH levels and number of bouts fought.

GH deficiency has been encountered more in retired than in active amateur male boxers. Retired boxers with GH deficiency have shown significantly lower pituitary volume than retired boxers with normal GH values.

Mean peak GH levels as well as mean IGF-1 levels have been significantly lower in boxers than in non-boxing controls.

EPO has increased significantly in venous blood of both iron- and placebo-treated boxers who performed endurance training during 18 days at moderate altitude (1800 m).

2) *Advice*

Analysis of data concerned by the present part of the review suggests the following advice.

Studies should better be performed to evidence possible correlations that link boxing career durations and/or number of bouts or rounds fought. The correlations could help advise a pugilist to end his boxing career when critical values thresholds have been reached, speaking of organs, hormones and other factors of the endocrine system [pituitary volume, adrenocorticotropic hormone (ACTH), growth hormone (GH), insulin-like growth factor-1 (IGF-1), …].

2.5. Cardiovascular Responses and Adaptations to Boxing Practice

The cardiovascular system is composed of blood, of vessels that contain the blood, and of the heart that pumps the blood through the vessels [9].

2.5.1. Blood Components

Blood consists of a suspension of cells in a fluid known as plasma [3]. The cells are red blood cells, white cells and platelets; plasma is made of water and solutes such as nutrients, respiratory gases, salts, hormones and proteins [3].

Serum is the fluid resulting from the removal of clot obtained after whole blood has been allowed to clot [50].

Hematocrit is the percentage of total blood volume that is red blood cells [49].

1) *Total Blood Creatine Kinase Isoenzyme BB*

There exist three common forms of isoenzymes of the enzyme referred to as creatine kinase: CK-BB (or CK-1) which is predominant in the brain tissue, CK-MB (or CK-2) which is predominant in the heart muscle, and CK-MM (or CK-3) which is predominant in the skeletal muscle [82].

Creatine kinase isoenzyme BB (CK-BB) is found in high concentrations in the brain but, in the blood, it is either normally undetectable or is present in low concentrations [83]. Blood CK-BB rose to significantly higher concentrations in 16 boxers than in 16 track cyclists as a result of measurements made before and after a fight for the boxers, but before and after a race for the cyclists [83]. Please see **Table 8**. Estimated in 8 of the boxers, the number of blows received to the head correlated significantly with the rise in CK-BB.

Blood concentrations of creatine kinase isoenzyme BB may thus be regarded as an indicator of brain damages in boxers.

2) *Total Blood Glucose*

Blood-borne glucose derives from liver glycogenolysis and gluconeogenesis, as well as from gastrointestinal tract when glucose is ingested [84]. With more details, it may be said that glucose is the blood principal carbohydrate; it is an aldo-hexose of formula $C_6H_{12}O_6$; during postprandial period, it may originate from drinks and foods; during fast period, it may originate from hepatic glycogenolysis, from skeletal muscle glycogenolysis, as well as from adipose tissue and liver lipids breakdown; and during prolonged fast period, if glycogen and lipid stores are almost finished, it may originate from cell proteins catabolism [3].

It is worth signaling that musculoskeletal glycogenolysis yields blood glucose indirectly: in anaerobic conditions, after hepatic gluconeogenesis of musculoskeletal glucose-derived pyruvate and/or lactate [3]. Gluconeogenesis may convert glycerol, lactate, and amino acids into glucose in order to delay depletion of liver or muscle glycogen [85].

Table 8. Influence of boxing practice on blood components.

Total blood creatine kinase isoenzyme BB concentration values		
before fight values	<	after fight values
Total blood glucose concentration values in amateur boxers, post-simulated bout on an ergometer		
restricted energy and fluid intakes diet values	=	normal diet values
Total blood lactate concentration values in amateur boxers, in response to simulated boxing on a prototype ergometer		
euhydrated state values	=	exercise-induced thermal dehydration values
restricted energy and fluid intakes diet values	<	normal diet values
Total blood lactate concentration values, during bout		
National level amateur competitive boxers		
mean value: 8.24 mmol·l^{-1}		
International amateur boxers, post-contest		
seniors		juniors
13.5 ± 2 mmol·l^{-1}		14.1 ± 2 mmol·l^{-1}
Total blood lactate concentration values in amateur boxers post-simulated bout on an ergometer		
post-massage intervention values	=	post-passive intervention values
Total blood hematocrit amateur boxers resting values		
seniors		juniors
48% ± 2%		45% ± 2%
Total blood hemoglobin amateur boxers resting values		
seniors		juniors
14.7 ± 1.0 g·dl^{-1}		14.5 ± 0.8 g·dl^{-1}
Total blood bilirubin amateur boxers resting values		
seniors		
15.3 ± 6.2 µmol·l^{-1}		
Total blood ferritin amateur boxers resting values		
seniors		
63.3 ± 45.7 ng·ml^{-1}		
Serum creatine kinase values increase in amateur boxers, post-performance		
shadow boxing values	<	real boxing values
Serum myoglobin values increase in amateur boxers, post-performance		
shadow boxing values	<	real boxing values
Serum glial protein S-100B values increase in amateur boxers, post-performance		
boxing sparring values	<	competition boxing values

a. "<" means "are lower than". b. "=" means "are not significantly different from". c. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

The effects of serial reductions in energy and fluid intake have been examined during simulated amateur boxing performance on boxing specific ergometer [86]. In a counterbalanced design, the subjects completed three 3-minute rounds interspersed with 1-minute recovery on days 3 and 5 of 5-day normal diet trial andon days 3 and 5 of 5-day restricted energy and fluid diet trial. The trials were separated by a 9-day period of normal dietary behavior. The subjects acted as their own controls. Blood glucose concentration determined 4-minute post-performance showed no significant difference between normal diet and restricted diet subjects, as signaled in **Table 8**.

During physical exercise, a drop or an increase in blood glucose may occur [85]. However, during the exercise, the organism tries its best to match up the resulting rise inhepatic glucose output and the increased glucose uptake by contracting skeletal muscle as long as there are sufficient stores of glycogen in the liver [85]. During recovery from exercise, compensatory reflexes may deal with exercise-induced glucose homeostasis disturbances [49].

During recovery from high-intensity exercise, gluconeogenesis contributes about 40% of hepatic glucose output which is sevenfold greater than during intense exercise [49]. Thus, both for intense exercise and for recovery from it, blood glucose benefits not only from gluconeogenesis but also from other sources (glycogenolysis…): normal diet subjects may have utilized both gluconeogenesis and other blood glucose sources for the task performed as well as for recovery from the task.

In the state of energy depletion, plasma lactate and pyruvate are elevated in exercising as well as in inactive muscle [49]. During exercise in an energy-depleted state, because of diminished muscle and liver glycogen stores, a rise in plasma glucose is possible but only by gluconeogenesis [49]. Hence, restricted energy and fluid diet subjects may have utilized lactate and other available gluconeogenic precursors both for the task performed and for recovery from the task.

Whatever the source of blood glucose that contributes to the restoration of the latter's pre-performance values, the result of the study here commented have shown that 4 minutes post-performance were sufficient for the same blood glucose concentration value to be shown by subjects of both normal and restricted energy and fluid diets.

3) *Total Blood Lactate*

In a skeletal muscle cell, lactate originates either when taken up from another skeletal muscle cell without appearing in the circulation [87] or from the cell own activity.

During skeletal muscle cell activity, when oxygen is insufficient to permit pyruvic acid enter the mitochondria, most of the acid is converted into lactic acid [18]. Under those conditions, lactate is the last product of glucose breakdown in the skeletal muscle cell [3].

Blood lactate originates from skeletal muscle cells lactate as a result of lactate diffusion out of the muscle cells into the interstitial fluid and then into the bloodstream [18].

Thermal Dehydration

With the purpose of making clear the effects of a body mass rapid loss immediately before weighing-in for competition in weight-governed sports, research workers had 7 novice amateur boxers complete a boxing-related task [88]. The boxers completed three 3-minute rounds of simulated boxing on a prototype boxing ergometer in a euhydrated state and after an exercise-induced thermal dehydration. Comparison between the euhydrated trial and the dehydration trial showed that body mass loss (3.8%) was statistically significant ($p < 0.001$); plasma volume fall (8%) was not statistically significant ($p > 0.05$); and blood lactate response to the boxing task did not differ, as signaled in **Table 8**.

Plasma volume decrease and blood lactate concentration could have been expected as both water deprivation and exercise may produce additive effects in plasma volume decline as well as in osmolality increase [49]. The results published by the research workers may be due to the existence of homeostatic signals of water and plasma volume deficit, which are communicated by autonomic afferent nerve fibers and hormones to brain centers or are detected directly by brain cells, and which result is correction of body water and plasma volume imbalances [49]. The results may also be due to the fact that in both euhydrated and dehydrated trial, there has been the same value resulting from lactate production, lactate release into the bloodstream and lactate removal from blood.

Energy and Fluid Intake Restriction

Another study examined the effects of serial reductions in energy and fluid intake on two simulated boxing performances separated by two days recovery [86]. Acting as their own controls, 8 amateur boxers simulated boxing bouts on a purpose-built ergometer. The two performances were separated by a 9-day period of normal diet. Each performance lasted 5 days and comprised simulated bouts on its days 3 and 5. Each bout consisted of three 3-minute rounds with 1-minute recovery. Each boxer performed a 5-day performance under normal energy and fluid intake and the other 5-day performance under restricted energy and fluid intake. Blood lactate and blood glucose were determined 4-minute post-performance. Body mass was maintained during normal diet but fell significantly (3%, $p < 0.05$) during the restricted diet. There was no significant difference in post-bout glucose values of normal compared to restricted diet performances. Post-bout blood lactate values were higher in the normal than in the restricted diet performances ($p < 0.05$), as signaled in **Table 8**.

The lack of significant difference between post-bout glucose values may be accounted for by the fact that during moderate-intensity to high-intensity exercise in an energy-depleted state, despite the muscle and liver glycogen stores diminution as well as the hepatic glucose production diminution, arise in plasma glucose is still possible but only by gluconeogenesis [49]. Four-minute post-performance may have been sufficient for restricted diet performance blood glucose to rise and reach the same value as that shown after normal diet performance.

During moderate to high intensity exercise in an energy-depleted state, plasma lactate and pyruvate are elevated in exercising as well as in inactive muscle [49].

What could explain the post-performance higher blood lactate values shown by the normal compared to restricted diet boxers is that the post-exercise period is characterized by the need to replenish degraded stores of muscle glycogen [84] while the energy-depleted state of restricted diet boxers had caused muscle and liver glycogen stores decrease, hepatic glucose production decrease, resort to gluconeogenesis for any rise in plasma glucose [49]. Moreover, 1) during moderate-intensity to high-intensity exercise in an energy-depleted state, plasma lactate is elevated [49], 2) lactate may be exported and transported by the bloodstream to some distant cell, which—depending on need and metabolic capacity—may use it as a source of energy or turn it into glucose by the process of gluconeogenesis [19]; and 3) as mentioned above, plasma lactate is elevated in moderate-intensity to high-intensity exercise in an energy-depleted state, while with acute exercise, lactate transport may increase with its concentrations as has been noticed in giant vesicles [obtained from intensively contracting muscles, at high lactate concentrations (20 mM) but not at low concentrations (1 mM)] [87]. Resort to gluconeogenesis for both blood glucose replenishment and muscle glycogen replenishment may have overused blood lactate in restricted diet, compared to normal diet performance boxers, with the resulting lower blood lactate values shown by the formers, compared with the latters.

National Level Boxers

During amateur boxing competitions, is 1-minute rest between boxing rounds sufficient to bring back blood lactate to warm up values? During those competitions, is boxing practice as overtaxing for one weight category boxers as for another one? That seems to be the case, as reflected by results published by a research team that utilized 26 senior national level amateur competitive boxers in the aim of exploring the aerobic-anaerobic metabolism as well as the training status of the athletes [28]. Among other results, neither inter-weight category nor inter-round differences have been observed in blood lactate concentration values, excepting in lighter weight boxers (48 - 57 kg) whose mean lactate levels in the second and third rounds were higher ($p < 0.05$) than in the first round. When all weight categories were pooled, blood lactate concentration value took the mean value of 8.24 $mmol \cdot l^{-1}$. Please see **Table 8**.

Increased blood lactate levels in the lighter weight boxers are understandable: 1) compared to the untrained, the trained subject resort to lipolysis in preference to glycogenolysis at the onset of exercise, what results in a glycogen sparingly use [10], 2) when muscle glycogenolysis has turned insufficient to help sustained exercise, lipolysis contributes to compensation for the loss in energy derived from glycogenolysis [10], and 3) the lighter the boxer, the lesser relative adiposity the boxer shows [89]. Hence, the lighter boxer's relative nimble behavior while boxing could possibly make him produce more blood lactate than the heavier boxer. In fact, having less fat stores, the lighter boxer could resort more rapidly on carbohydrate stores than the heavier at the onset of pugilistic work as well as when lipolysis-derived energy should replace glycogenolysis-derived energy when glycogen stores have turned insufficient to sustain pugilistic work. Resorting to glycogenolysis while nimbly boxing could raise blood lactate values, as when the production of pyruvate [and nicotinamide adenine dinucleotide (NADH)] increases above what can be handled by pyruvate dehydrogenase (PDH) and the malate-aspartate shuttle system [SS (carbohydrate oxidation)], the excess pyruvate and NADH are converted to lactate and NAD^+ by lactate dehydrogenase (LDH) [8].

Increased blood lactate levels in lighter weight boxers after the first round is also understandable as during prolonged exercise above the lactate threshold, blood lactate continuously rises, indicating a sustained rate of lactate production, a greater reliance on carbohydrate, and reduced lactate removal [84]. However, it is worth signaling that pugilistic work is an intermittent one.

International Level Boxers

England international amateur boxers have shown post-contest blood lactate values higher than those above mentioned (8.24 $mmol{\cdot}l^{-1}$, shown at the national level). The values [mean ± standard deviation] have been 13.5 ± 2 $mmol{\cdot}l^{-1}$ and 14.1 ± 2 $mmol{\cdot}l^{-1}$ in the senior and in the junior boxers, respectively, after four 2-minute round contests [27]. Please see **Table 8**. That suggests that ATP re-synthesis relies thus on anaerobic glycolysis more at the international level than at the national level in amateur boxers.

Massage Intervention

A study has been carried out with the aim of investigating the effect of massage on perceived recovery and blood lactate removal, as well as to examine the effect of massage on repeated boxing performance [58]. In the last of the three purposes, the research workers had 8 amateur boxers complete two performances on a boxing ergometer on two occasions in a counterbalanced design. Each of either performances was preceded by a 5-minute warm up. Sixty minutes separated the two performances. During the 20 first of the 60 minutes, some participants have been applied massage intervention by the same qualified sports massage therapist, while the remainder of participants had undertaken a passive rest intervention, lying on mats. Blood lactate was assessed before each of either warm ups; after each of either performances and after the 20-minute intervention (massage or no massage). Statistical analysis showed no differences in blood lactate or glucose following massage or passive rest interventions, as signaled in **Table 8**, although the blood lactate concentration after the second performance was significantly higher following massage ($p < 0.05$). Massage intervention comprised "effleurement", mistakenly named "effleurage" [90] by the research workers, (30 $strokes{\cdot}min^{-1}$) and "pétrissage" (50 - 60 $strokes{\cdot}min^{-1}$). "Effleurement" massage consisted of rhythmic pressure strokes along the longitudinal axis of each muscle group in a distal to proximal fashion. "Pétrissage" massage consisted of kneading and squeezing motions over the muscle mass.

One may take into account the facts that 1) contracting skeletal muscle causes compression of blood vessels, what results in lower blood flow [18]; 2) short periods of vascular occlusion are accompanied by oxygen deficit accrual [18]; and 3) in exercise in which oxygen delivery to contracting skeletal muscle is reduced (e.g., by hypoxia, anemia, CO exposure), the levels of blood and muscle lactate increase [84].

Thus, compared to those of passive intervention, higher post-massage blood lactate values may be expected if massage intermittent pressure strokes compress blood vessels; lower the concerned blood flow, what decreases blood lactate removal; cause relative oxygen deficit accrual; the sum of which yielding blood lactate increase.

However, the results obtained by the concerned research workers are in contradiction to the expectation. But what could explain the significant higher blood lactate values obtained after the second performance is that they may have resulted from addition of two no significant values: the first caused by massage intervention and the other due to the second performance.

It is worth signaling that blood lactate removal after exhausting exercise is enhanced if the subject continues to exercise, but at a lower intensity that normally does not produce any lactate [19].

4) *Total Blood Hematocrit*

Hematocrit is the percentage of blood volume that is occupied by erythrocytes [19].

England international amateur boxers showed the following hematocrit normal resting values: 48% ± 2% (senior boxers) and 45% ± 2% (junior boxers) [27]. Please see **Table 8**.

However, the research worker failed to specify the gender of the subjects enrolled in the study. Hematocrit range of both groups of subjects may be considered as normal if the latters are male [3] but are higher than most of the values comprised in the normal range of female resting values [3].

The mean hematocrit value of senior boxers is higher than that of junior. In the case that the boxers are male, that may be explained by the facts that 1) plasma testosterone values are higher in the age range of senior boxers (18 to 34 years old) than in the range of junior boxers (16 to 17 years old) [18], and 2) testosterone is able to increase red blood cell production [18]. Thus, the increased red blood cells number would have resulted in increased hematocrit value, assuming that plasma volume either no had changed, had decreased or had increased in proportion lesser to red blood cells number increase.

5) *Total Blood Hemoglobin*

Hemoglobin is the red pigment in the red blood cells [50], composed of heme and globin, which carries most of oxygen and part of carbon dioxide [3]. Hemoglobin also has an additional important role as an acid-base buffer, a regulator of hydrogen ion concentration, which is crucial to the rates of chemical reactions in cells [60].

England international amateur boxers showed the following hemoglobin normal resting values: 14.7 ± 1.0 $g \cdot dl^{-1}$ (senior boxers) and 14.5 ± 0.8 $g \cdot dl^{-1}$ (junior boxers) [27]. Please see **Table 8**.

What has been stated about blood hematocrit values relative to the boxers genders stay valid concerning the blood hemoglobin values. In fact, blood hemoglobin values shown by male subjects are higher than those shown by female subjects when both hematocrit and quantity of hemoglobin in each respective cell are normal [18].

Taking into account the facts that 1) hematocrit values are higher in senior than in junior, here concerned, boxers, 2) most of hemoglobin remains inside the blood cells [18], and 3) in normal people, the percentage of hemoglobin is almost always near the maximum in each cell, one may expect blood hemoglobin mean values higher in senior than in junior here concerned boxers.

6) *Total Blood Bilirubin*

Bilirubin is the product of biliverdin conversion and is excreted in the bile [50]. Biliverdin is the product of heme conversion after globin has been split off from the hemoglobin molecule, when old red blood cells have been destroyed by tissue macrophages [50].

England international amateur senior boxers showed the following bilirubin normal resting values: 15.3 ± 6.2 $\mu mol \cdot l^{-1}$ [27]. Please see **Table 8**.

After destruction of hemoglobin, the resulting porphyrin portion is converted into bilirubin which is released into the blood and later removed from the body by secretion through the liver into the bile [18].

As in the concerned subjects, hemoglobin values have been found normal (see 5) *Total Blood Hemoglobin*), normal bilirubin values could be expected. Such values could also have been shown by the subjects in either cases of increase or of decrease to the same extent of both hemoglobin degradation and bilirubin removal from the blood.

7) *Total Blood Ferritin*

Ferritin is the principal storage form of iron in tissues [19]. Except for the iron in the hemoglobin of the blood, by far the greatest proportion of iron in the body is stored in the liver in the form of ferritin [18]. Iron is also stored in the form of ferritin in tissues other than the liver [18].

England international amateur senior boxers showed the following ferritin normal resting value: 63.3 ± 45.7 $ng \cdot ml^{-1}$ [27]. Please see **Table 8**.

Finding normal ferritin values makes one expect no change in the tissues values of free iron that combines with apoferritin to form ferritin. That may result from changes to the same extent of the molecules which are at the same time sources and products of free iron.

Plasma transferrin as well as tissues ferritin, hemosiderin, heme and enzymes are those molecules [18].

8) *Serum Creatine Kinase*

The phosphagen system contributes to ATP provision primarily for short-term, high-intensity activities [59]. Composed of brief bouts of activity interspersed with one-minute rest, boxing activity is also concerned with that biological energy system. The energy provided by the system relies on the hydrolysis of the ATP molecule previously synthesized thanks to creatine kinase [59].

Creatine kinase is the enzyme that mediates the reaction of ADP phosphorylation from creatine phosphate so as to obtain ATP and creatine [9]: it is the enzyme that catalyzes the transfer of high-energy phosphate from creatine phosphate to ADP, what yields creatine and ATP [3].

That enzyme is normally located in the cytosol.

Marked changes encountered in the serum levels of myoglobin and creatine kinase in individuals subjected to very stressful work aimed a study performed on amateur boxers to measure the difference between shadow boxing (non-traumatic activity) and real boxing (traumatic activity) in terms of their effects on a number of humoral parameters [91].

Serum creatine kinase increased more after real boxing than after shadow boxing [91]. Please see **Table 8**.

That was to expect, taking into account what follows. Due to tissue damage or to increased membrane plasma permeability, a release of various tissue enzymes in the blood plasma may occur [33]. In the case of an extensive damage to the skeletal muscle tissue, an increase in the activity of the skeletal muscle creatine kinase isoenzyme may be observed in the plasma [33].

Hence, skeletal muscle plasma membrane damage associated with real boxing is largerthan that which is associated with shadow boxing.

9) *Serum Myoglobin*

Myoglobin is a protein that transports oxygen within the cell [6]; it is an iron-containing pigment that may provide oxygen in the skeletal muscle, oxygen that it has previously taken up fromhemoglobin [50].

An increase in muscle myoglobin concentration may facilitate aerobic metabolism [92].

When a skeletal muscle suffers micro-damages, the protein called myoglobin is released in the blood earlier than the skeletal muscle creatine kinase isoenzyme [33].

Serum myoglobin increased more after real boxing than after shadow boxing [91]. Please see **Table 8**. That suggests that skeletal muscle plasma membrane micro-damages associated with real boxing are larger than those which are associated with shadow boxing.

10) *Serum Glial Protein S*-100 *B*

S-100 B is a protein mainly found in astroglial cells and only detected to a low level in blood [93]. Serum levels of S-100 B protein increase in patients with acute brain injuries [93].

Serum glial protein S-100B levels have been assessed before and after amateur boxing competitions (n = 10) and boxing sparring bouts (n = 15); as well as before and after 25 km race (n = 11), jogging (10 km, n = 12), short term running (n = 12), and heading footballs (n =12) [94]. Here are some findings from the study: 1˚ competitive boxing and 25 km race caused higher ($p < 0.001$) increases of the serum glial protein S-100 B levels compared with the other disciplines (please see **Table 8**); 2˚ boxing sparring and running disciplines showed no significant ($p = 0.21$) difference in their respective increases; 3˚ the number and severity of the strikes to the head correlated significantly with the protein S-100 B levels increase; and 4˚ ergometer cycling and soft heading of footballs showed no increase in the glial protein S-100 B.

Thus, despite the fact that levels of S-100 B protein known to be associated with neuropsychological deficits were not reached in the study [94], increases in that protein are higher after amateur competitions than after boxing sparring bouts and could possibly be lesser in amateur than in professional boxing, as thought by the author of the study.

2.5.2. Cardiovascular Responses to Boxing Practice

Is cardiac what relates to the heart [2]. Here, is vascular what relates to the blood containing vessels.

1) *Heart Rate*

The heart is the pump that propels blood through the system of blood vessels [3]. Rate is the number of times something happens within a certain period [2]. Heart rate is an expression of the number of times the heart contracts in a specified unit of time [9]: heart rate refers to the number of times the heart beats per minute.

Cardiac output is the amount of blood pumped by the heart in liters per minute and is determined by the quantity of blood ejected with each beat (stroke volume) and the heart's rate of pumping (heart rate) [6].

Increase in cardiac output contributes to the satisfaction of some exercise-derived needs: 1) escalated muscle need for water, 2) greater delivery of nutrients and oxygen to contracting muscle, 3) faster waste and heat removal from the body… [49].

a) *Competitive Boxers Demand for Heart Rate*

Contrary to the period of rest and during exercise of light and moderate intensity when heart rate can be affected by various factors, during repeated maximal exercise, the heart rate is remarkably similar under various conditions, with a standard deviation of ±3 beats·min^{-1} [19].

That is reflected in the following. Measured during warm up and boxing rounds of competitive bouts in 26 senior national level amateur boxers, the heart rate showed neither inter-weight category difference nor inter-round difference, and took the mean value of 178 beats·min^{-1} when all weight categories were pooled [28], as signaled in **Table 9**.

b) *Boxing Speed and Heart Rate*

Heart rate increases linearly with increases in intensity during aerobic exercise [6]. Nevertheless, boxing is an intermittent activity that relies a 70% upon anaerobic processes and a 30% on aerobic processes towards total energy expenditure [4]. In boxing also, heart rate increase with increasing exercise intensity has been

Table 9. Influence of boxing practice on heart size and heart rate.

Heart size in national level boxers		
Heart volume	<	800 ml
Quotient heart volume (ml) per body weight (kg)		
national level boxers		untrained persons
12.7 ml·kg^{-1}		11.7 ml·kg^{-1}
Heart rate values means at the work load of 100 *watt*		
national level boxers		untrained persons
109.0 beats·min^{-1}		123.4 beats·min^{-1}
Heart rate values increase in boxers for the same submaximal work load		
high protein diet group and ordinary diet group values	<	free diet group values
Heart rate values in amateur boxers, in response to simulated boxing on a prototype ergometer		
euhydrated state values	=	exercise-induced thermal dehydration values
Heart rate values in amateur boxers, in response to simulated boxing on a prototype ergometer, post-performance		
restricted energy and fluid intake diet values	=	normal diet values
Heart rate values increase in trained volunteers, during fitness boxing trials at submaximal oxygen consumptions		
heart rate values range		concomitant punching tempo values range
167.4 - 182.2 beats·min^{-1}		60 - 120 b·min^{-1}
Heart rate values in amateur boxers, during bout		
senior national level mean values: 178 beats·min^{-1}		

a. "<" means "are lower than". b. "=" means "are not significantly different from". c. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

found.

In fact, as signaled in **Table 9**, heart rate measured continuously increased significantly ($p < 0.05$) with values ranging from 167.4 to 182.2 beats·min^{-1}, or 85% to 93% of maximum heart rate, between trials with increasing punching tempos (60, 72, 84, 96, 108 and 120 b·min^{-1}) of 2-minute randomized fitness boxing trials in 18 trained volunteers (12 men and 6 women) [age = 22.0 ± 2.8 years, height = 170.79 ± 7.67 cm, weight = 71.54 ± 12.63 kg (means ± SD)] wearing 0.34-kg punching gloves [13]. The concomitant oxygen consumption values ranged from 26.83 to 29.75 ml·kg·min^{-1}, or 67.7% to 72.5% of maximal oxygen consumption.

c) *Heart Rate and Exercise-Induced Thermal Dehydration immediately before Weighing-In for Competition*

An exercise-induced thermal dehydration failed to affect heart rate despite a statistically significant mean body mass loss of 3.8 (SD ± 0.3) % [77.3 (SD ± 11.3) to 74.4 (SD ± 10.7) kg, $p < 0.001$] in 7 novice amateur boxers who completed three 3-minute rounds of simulated boxing on a prototype boxing ergometer in a euhydrated state and after the dehydration [88]. Please see **Table 9**.

As cardiac output equals stroke volume times heart rate [6], the lack of heart rate difference between euhydrated state trial boxers and exercise-induced thermal dehydration boxers could have resulted from a stroke volume lesser in the former boxers than in the latter, for the same expected boxing-related-task-induced increased cardiac output.

d) *Heart Rate and Rapid Weight Reduction Period* (9 *days*) *immediately before Boxing Competition*

Astudy undertaken with the purpose of providing information on nutrition requirement during rapid weight reduction (9 days) immediately before boxing competition yielded among other results that, at the same submaximal work load, heart rate and oxygen intake increased significantly in the free diet group (food taken ad libitum), contrary to the high protein diet group and the ordinary diet group [17] where no noticeable changes was observed, as signaled in **Table 9**. During the first half of weight reduction period, 1) high protein diet boxers had to take 2.0 $g \cdot kg^{-1} \cdot day^{-1}$ of protein and 2000 $kcal \cdot day^{-1}$, while ordinary protein diet boxers had to take 1.0 $g \cdot kg^{-1} \cdot day^{-1}$ of protein and 2000 $kcal \cdot day^{-1}$. During the second half of reduction weight period, 1) in free diet boxers, average intake resulted to have been 0.9 $g \cdot kg^{-1} \cdot day^{-1}$ of protein and 883 $kcal \cdot day^{-1}$; 2) high protein diet boxers had to take 1.5 $g \cdot kg^{-1} \cdot day^{-1}$ of protein and 1200 $kcal \cdot day^{-1}$; while 3) ordinary protein diet boxers had to take 1.0 $g \cdot kg^{-1} \cdot day^{-1}$ of protein and 1200 $kcal \cdot day^{-1}$.

As far as protein consumption is concerned, the values shown by the free diet group and the ordinary diet group diet seem normal [19] [20] while, in the high protein diet group, the values show a 100% increase in the first and a 50% increase in the second halves of the weight reduction period, compared with the requirement for dietary protein for all individuals, performing exercise or not, aged 19 years and older (0.8 g for Phillips *et al.* and 1.0 g for Åstrand *et al.* [19] [20]).

When energy consumption is concerned, compared with the daily requirement for a very sedentary man performing only essential functions (2000 $kcal \cdot day^{-1}$) [18], to which has been often observed in most athletes an increase by more than 1200 $kcal \cdot day^{-1}$ [19], the values shown by the three groups of boxers are reduced, relatively in the first half of the weight reduction period or absolutely in the second half of the period.

Contrary to the high protein diet and the ordinary protein diet boxers, free diet boxers have shown a change in the nitrogen balance to a negative value. Protein degradation could possibly have taken place due to the reduced calorie intake (carbohydrate and fats are protein sparers which are utilized for energy purposes in preference to protein utilization [18])

The low energy intake and the resulting protein utilization for energy purposes may have turned more overtaxing in the free diet group than in the high and in the ordinary protein diet groups the same submaximal work load assigned to each of the three groups. Then, the positive correlation ($r = 0.87$, $p < 0.01$) that links the rating of perceived exertion to the oxygen consumption ($\dot{V}O_2$) [16] explains the increase, exclusively in the free diet group, of the oxygen consumption ($\dot{V}O_2$), which, in turn, explains the heart rate increase only in the free diet group, contrary to the situation in the two other groups. In fact, maximal as well as submaximal values being taken into account, there has been shown a trend towards increasing heart rate values with increasing oxygen uptake ($\dot{V}O_2$) [19].

e) *Heart Rate Not Influenced by Energy and Fluid Intake Restriction*

Eight amateur boxers who acted as their own controls [age: 23.6 ± 3.2 years, height: 175 ± 5 cm and body mass: 73.3 ± 8.3 kg (mean ± SD)] had to complete two trials, each made of one bout on day 3 and another one on day 5 of each trial [86]. One of the trials took place under normal diet and the other under restricted diet (energy and fluid intake restriction). The two 5-day trials were separated by a 9-day period of normal dietary behavior. Each bout was performed using a purpose-built boxing ergometer and comprised three 3-minute rounds interspersed with one-minute recovery. Body mass was maintained during the normal diet trial but fell significantly (3%, $p < 0.05$) during the restricted diet trial. Despite the body mass fall, there was no significant difference in end-of-bout heart rate, as signaled in **Table 9**.

The lack of significant difference in the heart rate value supports what has been noticed: during maximal exercise, the cardiac output, oxygen uptake, and heart rate are remarkably fixed to values typical for the individual even if the performance is made under adverse conditions [19] (here, energy and fluid intake restriction during three to 5 days constitute adverse conditions).

In amateur boxers, exercise-induced thermal dehydration caused a statistically significant body mass loss (3.8%, $p < 0.001$) but failed to induce a plasma volume loss [88]. However, the body mass loss was rapid, contrary to the loss dealt with here that took place due to days of energy and fluid intake restriction [86]. Could that make expect a plasma volume loss, a decreased venous return, and changes in the stroke volume and heart rate values?

Cardiac output equals stroke volume multiplied by heart rate. As many different physiologic effects occur at the same time during exercise to increase cardiac output approximately in proportion to the degree of exercise [18] and as the subjects, acting as their own controls have had to perform exactly the same task during both the normal and the restricted diet trials, cardiac output may be considered to show the same value in both trials.

Hence, the same value shown by the heart rate in both trials implies that the stroke volume also shows the same value in both trials. But is that possible despite the expected plasma volume loss derived from energy and fluid intake restriction? That is possible taking into account 1) that among the factors that may increase the stroke volume, there are greater venous return and increased arterial pressure (in the aorta or the pulmonary artery) [19]; and 2) that the restricted diet could possibly have triggered a reactive secretion of stress hormones through dehydration, hypovolemia and psychological distress; with the resulting increase in arterial pressure.

In fact, during intense physical effort, hormones are secreted in a reactive fashion to nonspecific events [49]: 1) dehydration, for instance, elicits increased release of norepinephrine, cortisol and arginine vasopressin, while 2) both hypovolemia and psychological distress trigger, among other hormones, increased secretion of norepinephrine, epinephrine and cortisol, but 3) hypovolemia elicits also a decreased secretion of atrial natriuretic peptide [49]. On the other hand, blood pressure and cardiac output may increase due to increases in norepinephrine, epinephrine and arginine vasopressin secretions as well as decrease in atrial natriuretic peptide secretion, while increase in cortisol secretion may result in blood pressure increase [49]. The possible increased arterial pressure could have counterbalanced the possible decrease in the venous return during the restricted diet trial, what has yielded no difference in heart rate values, when comparison has been made between the normal and restricted diet trials.

2) *Plasma Volume*

The plasma is the extracellular fluid of the blood [19].

During brief exercise above 40% of $\dot{V}O_2max$ that is too short (6 minutes) to elicit significant water and sodium losses through sweating, plasma volume declines and its osmolality increases; hypovolemia develops in proportion to exercise intensity [49].

Due either to the intermittent characteristic of boxing activity or, as signaled by the authors of the concerned study, due to the smallness of the sample, the decrease in plasma volume failed to manifest itself.

In fact, in 7 novice amateur boxers employed to examine the effects of exercise-induced thermal dehydration on plasma volume by completing three 3-minute rounds of simulated boxing on a prototype boxing ergometer in euhydrated state and after the boxing dehydrating task, inconsistent plasma volume changes were found despite a statistically significant body mass loss (3.8%, $p < 0.001$) due to the boxing related task. The plasma volume showed a non-statistically significant decrease [8.0 (SD ± 17.2) %, $p > 0.05$] when the expected dehydrated state value has been compared to its value in the euhydrated state [88]: 4 subjects suffered plasma volume reductions ranging from 15% to 30%, one subject maintained his euhydratedstate value while two recorded an increase.

2.5.3. Cardiac Adaptations to Boxing Practice

Is cardiac what relates to the heart [2]. Heart is the pump that propels blood through the system of blood vessels [3].

1) *Heart Size*

Size is how big or small something is [2]. Here, the heart is concerned.

In active athletes, there is a correlation between the demand placed on oxygen transport system by the event in question and the estimated heart volume such as the higher the demand, the higher the heart volume: on average, the volume is below 800 ml for boxers (please see **Table 9**) and sprinters, between 800 and 900 ml for middle-distance runners, and above 900 ml for long-distance runners, for instance [19].

In the ECG of male boxers, left ventricular hypertrophy has been encountered with an incidence of 33.3% [95].

Compared to 50 untrained normal persons of the same age, 18 boxers belonging to the national team of Germany showed a significant increase in the quotient heart volume (ml) per body weight (kg): 11.7 $ml \cdot kg^{-1}$ vs. 12.7 $ml \cdot kg^{-1}$ ($p < 0.05$) (C VIII a 1967) [96]. That appears in **Table 9**.

2) *Electrocardiogram*

Electrocardiogram (ECG) is the graphic representation resulting from the recording of the electrical potentials generated by the depolarization and repolarization of the cardiac muscle, the electrodes being placed on the skin [74].

An ECG tracing is composed of waves, segments and intervals: 1) the P wave which records depolarization of the two atria; 2) the Q wave, the R wave and the S wave which together are called the QRS complex, even when the Q wave or the S wave are missing, that records the depolarization of the ventricles; 3) the T wave which records the ventricles repolarization; 4) the PQ segment which lasts as long as the atria are fully depolarized; 5) the ST segment which lasts as long as the ventricles are fully depolarized; 6) the PQ interval which lasts from the beginning of the atria depolarization to the beginning of the ventricles depolarization; 7) the QT interval, heart rate-dependent, which lasts from the beginning of the ventricles depolarization to the end of the ventricles repolarization, etc.

QTc refers to the QT interval after it has been measured and corrected for changes in the heart rate [97].

Normally, the process that leads to total depolarization of the ventricles alternate with the process that leads to total repolarization of the ventricles. There exists thus one moment when ventricles become totally repolarized. Nevertheless, sometimes, when the heart muscle suffers from a damage, the heart is unable to totally repolarize: permanent depolarization takes place in the injured areas of the heart muscle (in the areas of the heart muscle damage), even between heartbeats.

The resulting current that flows between the pathologically depolarized and the normally polarized areas even between heartbeats is called a current of injury [18].

Current of injury may result from mechanical trauma, infectious processes, and ischemia of local areas of heart muscle caused by local coronary occlusions [18].

In the ECG, the J point represents the exact point at which the wave of depolarization just completes its passage through the heart, which occurs at the end of the QRS complex; the point at which all parts of the ventricles have become depolarized, including both the damaged parts and the normal parts; the point at which no current is flowing around the heart, even the current of injury; the point at which the potential of the electrocardiogram is at zero voltage [18].

Sportspersons generally show a normal ECG [10]. However, the normal ECG response to exercise include, among other things, 1) superimposition of the P and the T waves of successive beats, 2) increases in T wave amplitude (although wide variability exists among subjects), 3) minimal shortening of the QRS duration, 4) depression of the J point, and 5) rate-related shortening of the QT interval [98].

Do boxing practitioners share all the components of the normal ECG response to exercise with sportspersons in general?

In a study undertaken to analyze the presence of myocardial damage in relation to official boxing matches, a standardized ECG before, immediately after, one hour and 12 hours after the match were obtained from each of 15 amateur boxers participating in the semifinals of the Italian Championship to analyze atrio-ventricular conduction, QRS axis and duration, as well as atrio-ventricular repolarization [99]. Significant changes were encountered after the fight: higher QRS voltages, lowering of the J point and ST segment in lateral leads, higher ST slope, lower T wave amplitude, shorter T wave peak time, and shorter QT interval. When the last two parameters were corrected for heart rate, no differences were observed for QTc, while T wave peak time significantly increased. All the changes persisted until one hour after the match. Furthermore, 20% of boxers showed marked ventricular repolarizations anomalies in lateral leads after the bout, persisting for 12 hours in one case (about 7% of boxers). The authors of the study pointed out that, despite the absence of myocardial damage signs, the ventricular repolarization anomalies took place in lateral leads after the bout and persisted 12 hours in one case.

The results of the above mentioned study show that the concerned boxers share with the other sportspersons the depression of the J point as well as the shortening of the QT interval to which may possibly have contributed shortening of the QRS complex, but on the other hand, the boxers show a decrease in the T wave amplitude [99] while the other sportspersons show an increase in the T wave amplitude [98].

Higher QRS voltages signaled in the above mentioned study may be expected in male boxing practitioners as 33.3% of them may show left ventricle hypertrophy [95] while the cause of high-voltage QRS complexes most often is increased muscle mass of the heart, which ordinarily results from hypertrophy of the muscle in response to excessive load on one part of the heart or the other [18]. The increased quantity of muscle causes generation of increased quantities of electricity around the heart, with the resulting electrical potentials recorded in the electrocardiographic leads considerably greater than normal [18].

T wave repolarization anomalies may result either from exercise-induced myocardial ischemia [18] or from ventricular repolarization anomaly [100]. In the boxers concerned by the study, is the anomaly found in the T wave amplitude due to myocardial ischemia or to anomaly in ventricular repolarization?

Up-sloping ST segment is 1) more the outcome of ventricular repolarization anomaly than that of exercise-induced myocardial ischemia [98], and 2) less indicative of myocardial ischemia than horizontal or down-sloping ST segment [98]. The higher ST slope shown in the study results suggests that ventricular repolarization anomaly underlies the T wave anomaly found in the boxers here concerned. The authors of the study state that, despite the ventricular repolarization anomaly, no clinical sign of myocardial damage was found [99]. However it is worth signaling another possible cause of ST segment up-sloping when it results from a J point depression: competition between normal repolarization and delayed terminal depolarization forces, but here also, more than myocardial ischemia [98].

3) *Heart Rate*

Rate is the number of times something happens within a certain period [2]. Heart rate refers to the number of times the heart beats in a specified unit of time [9].

Boxing practice comprises both endurance and resistance training and its total energy expenditure derives from both aerobic and anaerobic processes. Endurance as well as resistance training may result in decreased resting and exercise heart rates as one of cardiovascular adaptations [101]: at a work load of 100 watt, a significant heart rate (HR) decrease has been encountered in 18 boxers of the national team of Germany when compared to 50 untrained normal persons of the same age (109.0 vs. 123.4 pulse rate, $p < 0.001$) [96], as signaled in **Table 9**.

2.5.4. Reminder and Advices

1) *Reminder*

Boxing fight has caused a rise in total blood creatine kinase isoenzyme BB, rise which significantly correlated with the number of blows received.

Four minutes post-simulated amateur boxing performance have been sufficient for total blood glucose concentration to show no significant difference between normal diet boxers and boxers who have been subjected to a restricted energy and fluid diet.

Exercise-induced thermal dehydration immediately before a simulated boxing trial did not affect total blood lactate response, nor plasma volume, despite a significant body mass rapid loss.

Energy and fluid intake restriction affected total blood lactate concentration such as 4 minutes post-simulated amateur boxing performance, values shown were higher in normal diet than in restricted diet subjects. Restricted diet caused significant body mass loss in the concerned boxers but post-bout total blood glucose values did not differ between normal diet and restricted diet boxers.

One-minute rest between boxing rounds has been sufficient to bring back blood lactate to warm up values, during amateur boxing competitions.

National level amateur boxers showed neither inter-round nor inter-weight category differences in total blood lactate concentration values when inter-round rest lasted one minute, excepting in lighter weight boxers whose mean blood lactate levels in the second and third rounds were higher than in the first round. When all weight categories were pooled, blood lactate concentration took the value of 8.24 $mmol \cdot l^{-1}$.

International level amateur boxers have shown post-4 two-minute round contests, total blood lactate values of (mean ± standard deviation) 13.5 ± 2 $mmol \cdot l^{-1}$ and 14.1 ± 2 $mmol \cdot l^{-1}$ in the senior and the junior boxers respectively.

Massage intervention and passive rest intervention after performance on a boxing ergometer did not cause any difference in total body lactate concentration values, except for the interventions after the second performance that took place 60 minutes after the first one, interventions following which massage caused significantly higher total blood concentration values.

In international amateur boxers, the following resting values have been found: 1) total blood hematocrit: 48% ± 2% (senior boxers) and 45% ± 2% (junior boxers), 2) total blood hemoglobin: 14.7 ± 1.0 $g \cdot dl^{-1}$ (senior boxers) and 14.5 ± 0.8 $g \cdot dl^{-1}$ (junior boxers), 3) total blood bilirubin: 15.3 ± 6.2 $\mu mol \cdot l^{-1}$ (senior boxers), and 4) total blood ferritin: 63.3 ± 45.7 $ng \cdot ml^{-1}$ (senior boxers).

Serum creatine kinase as well as serum myoglobin increased more after real boxing than after shadow boxing performed by amateur boxers.

Serum glial protein S-100 B levels increased significantly in amateur boxers after competitions while they did not increase significantly after boxing sparring bouts. When the increases occurred, the levels correlated significantly with the number and severity of the strikes to the head.

Electrocardiograms obtained from amateur boxers participating in semifinals showed that the concerned boxers shared with the other sportspersons the depression of the J point as well as the shortening of the QT interval to which may possibly have contributed shortening of the QRS complex, but on the other hand, the boxers showed a decrease in the T wave amplitude while the other sportspersons show an increase in the T wave amplitude.

Low energy intake (only 1200 $kcal \cdot day^{-1}$, instead of much more for any athlete) increased significantly boxers' heart rate values for the same submaximal workload.

Boxing speed increase caused significant increase in heart rate values which were all submaximal values as were the concomitant oxygen consumption values.

Both boxing competition and simulated boxing on ergometers failed to increase heart rate in amateur boxers.

Plasma volume showed inconsistent changes in amateur boxers who intended exercise-induced thermal dehydration by simulating boxing on an ergometer.

In boxers, the following adaptations have been encountered: 1) heart volume has measured 800 ml, 2) left ventricular hypertrophy has occurred with an incidence of 33.3%, 3) an increase in the quotient heart volume per body weight has been signaled, and, 4) at a workload of 100 watt, a significant heart rate decrease has been encountered.

2) *Advices*

Analysis of data concerned by the present part of the review suggests the following advices.

Studies should be carried out so as to evidence possible correlations that could link the duration of the pugilistic careers with the concentrations of some blood components of interest. In fact, post-real boxing bouts, increases of concentrations have been noted in total blood creatine kinase isoenzyme BB, serum creatine kinase, serum myoglobin and serum glial protein S-100B. In some cases, those increases have been related to the number of blows received and in one of those cases the increase has also been related to the severity of the strikes to the head. The expected correlations could help to advise a pugilist to end his boxing career when any, some or all the blood components of interest have reached the critical concentration thresholds.

Studies should be performed so as to show the possible pertinence of increasing the inter-round rest duration for lighter weight boxers (48 - 57 kg) and/or for junior boxers.

As competition draws near, comparisons should be drawn between blood components actual values shown by the boxers and the values recorded as normal when boxers are resting, so as to prevent possible boxing performance impairment due to large discrepancies between both kinds of values.

One should make sure that lowering the boxer's energy intake does not reach the threshold from which ideal pugilistic performance may be impaired.

2.6. Urinary Tract Responses to Boxing Practice

A tract is a system of connected organs that have one main purpose in a part of the body [2]. Urinary tract is comprised of the two kidneys, the two ureters, the bladder and the urethra [3].

Urinary tract is important in 1) maintaining the body water and electrolyte balance; 2) maintaining the acid-base balance; 3) regulating the urine volume and composition; 4) regulating the blood volume and blood pressure, and 5) eliminating waste products from the blood [40].

2.6.1. Osmolality

Osmolality expresses the concentration of a solution in terms of numbers of osmotically active particles per kg of water [18]. Here, each solute present in the solution is fully dissociated, if able to ionize.

Plasma osmolality may increase with increasing exercise intensity as well as with increasing dehydration [49]; the effects of exercise and water deprivation being additive [49]. Plasma osmolality increase causes excretion of concentrated urine while osmolality decrease is responsible for excretion of large amounts of diluted urine [3]. The human kidney can produce a maximal urine concentration of 1200 to 1400 $mOsm \cdot l^{-1}$, 4 to 5 times the osmolarity of plasma [18]. Urine osmolality may thus reflect the hydration or the dehydration status of boxers as dehydration may result successively in plasma osmolality increase and urine osmolality increase.

From Senior as well as from Junior England international amateur boxers, morning urine samples were collected over periods lasting from three to 18 days [27]. Some of the samples were collected immediately prior to and during competition, while others were collected during training camps. In any case of collection, samples showed osmolality values > 800 $mOs \cdot kg^{-1}$, values that reflect dehydration [27].

Those results suggest that noticeable boxer dehydration is obtainable from as low as a three-day period of fluid intake restriction.

2.6.2. Sport-Related Hematuria

Hematuria is urinary tract bleeding and may be due to a trauma, to kidney stones, to an infection or to a neoplasm [3]. When hematuria is concerned, the abnormal constituents found in the urine are the red blood cells [3]. Although micro-hematuria is quite common in the general population, it is even more common in athletes after exercise [19].

The pathophysiology may be either traumatic or non-traumatic [102]. Traumatic, the hematuria may result from vascular lesions due to renal trauma and/or bladder injury caused by repeated impact of the posterior bladder wall against the bladder base [102]. Non-traumatic, the hematuria may result from increased excretion of erythrocytes in the urine due either to 1) an increased exercise-induced vasoconstriction of the splanchnic and renal vessels so as to redistribute blood to contracting skeletal muscles, what causes an increase in glomerular permeability; or to 2) a relatively more marked constriction of the efferent glomerular arterioles that increases the filtration pressure [102].

Sport-related hematuria has been signaled in boxing practitioners [102].

2.6.3. Sport-Related Proteinuria

Proteinuria is the presence of protein in the urine [19].

The mechanism of sport-related proteinuria is the same as that of non-traumatic hematuria [102]. The urine is generally protein-free one to two days after the exercise [19].

Proteinuria is almost inevitable during strenuous or prolonged heavy exercise, and has been documented also in boxing practitioners [19].

2.6.4. Reminder and Advices

1) *Reminder*

Noticeable boxer dehydration has been obtained from as low as a three-day period of fluid intake restriction.

Sport-related hematuria has been signaled in boxing practitioners.

Proteinuria is almost inevitable during strenuous or prolonged heavy exercise, and has been documented also in boxing practitioners.

2) *Advices*

Analysis of data concerned by the present part of the review suggests the following advices.

Boxer dehydration should not exceed a period of approximately three days.

Techniques should better be developed so as people be able to discriminate between boxing-induced and non-boxing-induced hematuria and/or proteinuria.

2.7. Respiratory Response and Adaptations to Boxing Practice

Something is said pulmonary when it is related to the lungs, or has an effect on the lungs [2]. Something is said respiratory when it is related to breathing or to the lungs [2].

2.7.1. Respiratory Response to Boxing Practice: Pulmonary Ventilation

Respiratory minute ventilation, also referred to as pulmonary ventilation [50], means the inflow and outflow of air between the atmosphere and the lung alveoli per minute [18].

In the results obtained from 18 trained volunteers [12 men and 6 women of (mean ± SD) age 22.0 ± 2.8 years, height 170.79 ± 7.67 cm and weight 71.54 ± 12.63 kg)] who participated in two-minute randomized fitness boxing trials, wearing 0.34-kg punching gloves, at various punching tempos (60, 72, 84, 96, 108 and 120 $b \cdot min^{-1}$) [13], it appeared that, with increasing punching tempo, there were no significant increase in oxygen uptake but a significant increase in respiratory minute ventilation [13]. Please see **Table 10**.

Table 10. Influence of boxing practice on respiratory variables.

Respiratory minute ventilation increase in trained volunteers, during fitness boxing trials at submaximal oxygen consumptions	
respiratory minute ventilation values	concomitant punching tempo values range
increasing	60 - 120 $b \cdot min^{-1}$
Vital capacities values	
boxers	sedentary persons
4.52 ± 0.80 l, BTPS	3.61 ± 0.67 l, BTPS
Maximal voluntary ventilation (*MVV*)	
boxers	sedentary persons
146.0 ± 38.6 $l \cdot min^{-1}$, BTPS	110.5 ± 23.2 $l \cdot min^{-1}$, BTPS
Forced expiratory volume during the first second (*FEV* 1.0)	
boxers	sedentary persons
88.1% ± 6.7%	84.0% ± 6.8%

a. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

At 60 b·min^{-1} tempo, the threshold at which the ventilation increases proportionally more than the oxygen uptake had possibly been already reached while the ventilation increase was going on steeper. In fact, after the maximal oxygen uptake is reached, it is still possible for the subject to continue to exercise at higher rates because of the anaerobic processes [19]. At the same time, the pulmonary ventilation is increased markedly, without any distinct ceiling being reached except in some extreme cases [19].

2.7.2. Respiratory Adaptations to Boxing Practice

1) *Vital Capacity* (*VC*)

Vital capacity is the maximal amount of air a person can expel from the lungs after first inspiring to the maximum extent and then expiring to the maximum extent [18] [19]. It hence represents the approximate useable capacity of the lungs [12].

Several authors have reported that vital capacity is higher in athletes than in non-athletes of similar body size [12]. That has also been the case in 9 Indian boxers who showed (mean ± standard deviation) vital capacity values significantly ($p < 0.05$) higher (4.52 ± 0.80 l, BTPS) than those shown by 10 sedentary persons (3.61 ± 0.67 l, BTPS) [103], as signaled in **Table 10**. There was no significant difference between values shown by both samples, speaking of age, height and weight.

What follows may contribute to the explanation of the situation.

Both arterial partial pressure of oxygen and arterial partial pressure of carbon dioxide are among the variables that alter ventilation, already at rest [10]. At rest, arterial partial pressure value of oxygen in sportspersons is lower than the one that is shown by sedentary persons; conversely, arterial partial pressure value of carbon dioxide in sportspersons is higher than the one that is shown by sedentary persons [10]. Moreover, at rest, a decrease in arterial partial pressure of oxygen causes a moderate increase in ventilation, whereas a lowering of arterial partial pressure of carbon dioxide reduces respiratory activity [19]. Thus, before inspiring to the maximum extent and then expiring to the maximum extent (at rest) the amount of air expelled from the lungs is already higher in sportspersons than in sedentary persons, partly because of lower partial pressure value of oxygen and higher partial pressure value of carbon dioxide in the formers than in the latters.

In addition, boxing training is comprised of technical, tactical, psychological and physical parts in which intervene muscular activity. Regular muscular activity may result in strength and power output improvements of concerned muscles: heart muscle, limbs muscles and respiratory muscles, among others. Hyperpnea, the increase in depth and rate of respiration, may occur during exercise [19] and, in boxing, after completing a series of attacks and/or defenses techniques as well as after the end of a boxing round. Boxing attacks are concomitant of forced expiration. In boxers, an adaptation may thus take place such as respiratory muscles in general and expiratory muscles in particular benefit from an increase in strength and power output, with the resulting increase in the maximum amount of air the boxers can expel from the lungs, both at rest ad after maximal inspiration followed by maximal expiration (after vital capacity).

2) *Maximal Voluntary Ventilation* (*MVV*)

Also referred to as maximal breathing capacity [19], maximal voluntary ventilation is the largest volume of gas that can be moved into and out of the lungs in one minute by voluntary effort [50]. Its determination may help evaluate the mechanical properties of the lungs and chest wall [19].

Another result from the aforementioned study [103] is that the 9 Indian boxers showed (mean ± standard deviation) maximal voluntary ventilation values significantly ($p < 0.05$) higher (146.0 ± 38.6 $l \cdot min^{-1}$, BTPS) than those shown by the 10 sedentary persons (110.5 ± 23.2 $l \cdot min^{-1}$, BTPS), as signaled in **Table 10**.

The increase in maximal voluntary ventilation was to expect as there was an increase in the maximum amount of air the boxers can expel from the lungs, both at rest and after maximal inspiration followed by maximal expiration (after vital capacity). It had been signaled that maximal voluntary ventilation is among the functional ventilation variables which are manifestly increased, already at rest, during forced ventilation tests [10].

3) *Forced Expiratory Volume during the First Second* (*FEV* 1.0)

Forced expiratory volume is the maximal volume expired in one second [52]; it is the percentage of the individual's entire vital capacity that can be exhaled in the course of one second [19].

An increase in the vital capacity values make expect thus an increase in the values of the forced expiratory volume during the first second. But that was not witnessed by the values measured in the aforementioned 9 Indian boxers and 10 sedentary persons [103]. There was no significant difference between the values shown by both samples: 88.1% ± 6.7% in the boxers and 84.0% ± 6.8% in the sedentary persons, as signaled in **Table 10**.

What mentioned below may contribute to the explanation of the situation.

Speaking of the forced expiratory volume during the first second, it has been stated that the maximal flow is limited not only by the rate by which the muscles are able to transform chemical energy into mechanical energy but also by a rising flow resistance [19]. Additionally, expiration during quiet breathing is passive in the sense that no muscles that decrease intra-thoracic volume contract while some contraction of the inspiratory muscles that occurs in the early part of expiration exerts a breaking action on the recoil forces and slows expiration [50]. Thus, possibly, compared with what may have happened in the sedentary persons, trained inspiratory muscles of the boxers may have caused a higher breaking action on the recoil forces and hence a higher slowing action of the early part of forced expiration, during its first second among others, with the resulting prevention of the expectable increase in the boxers forced expiratory volume values.

2.7.3. Reminder and Advice

1) *Reminder*

At a given threshold, boxing punching tempo increase has resulted in respiratory minute ventilation increase, without significant increase in oxygen uptake.

Vital capacity, as well as maximal voluntary ventilation, has been found significantly higher in boxers than in sedentary persons.

Forced expiratory volume during the first second did not differ between boxers and sedentary persons.

2) *Advice*

Analysis of data concerned by the present part of the review suggests the following advice.

Assessing the suitability of boxers to meet competition demand could rely, among other tests, upon vital capacity (VC) and maximal voluntary ventilation (MVV) determinations, comparing the boxers' values of the moment with the boxers' usual values.

3. Recovery, Weight Control, Dietary Supplementation, Childhood, Gender, Altitude, Life Expectancy and Faith

Recovery, weight control, dietary supplementation, childhood, gender, altitude, life expectancy and faith are going to be dealt with next.

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In fact, he had already read and studied books dealing with physiology of sports in broad terms. When the opportunity came for him to read *Physiology of Sports*, he seized it. On finishing reading the *Contents* in the early pages of the edited book, he was disappointed that boxing practice was not concerned with any of the parts of the *Contents*. Nonetheless, in a late page of the edited book, the editors had expressed the hope that specialists whose sports had not been examined in any detail would be helped by the form of analysis used for sports covered in the edited book.

That prompted him to undertake the task of writing the present review which, he wishes, is not going to be his last.

Conflicts of Interest

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

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