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Boxing Practitioners Physiology Review: 4. Faith, Life Expectancy, Gender, and Childhood

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Abstract

The present journal paper is the fourth and last part of a review of boxing practitioners' physiology. The third part has dealt with dietary supplementation, weight control, recovery, and altitude. The second part has dealt with boxing practice-derived systemic responses and adaptations. The first part has dealt with kinanthropometric parameters, skeletal muscle recruitment, and ergometry. Search engines and printed documents have helped gather the information that has been discussed in the present and fourth part: as far as boxing practice is concerned, information relating to 1) faith, 2) life expectancy, 3) gender, and 4) childhood. 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 consultation of the tables that are positioned in the text, not forgetting the reminders, advice, and suggestions that appear at the end of each of the four parts of the journal paper (2.5.2., 2.5.3., 2.6.2., 2.6.3., 2.7.3., 2.7.4., 2.8.6., and 2.8.7.). The reader's attention is drawn 1) to the fact that faith is possibly a factor that may influence the performance of a boxer, but not the only one, 2) to the fact that more research work related to life expectancy is still to be carried out, 3) to the fact that females appear less negatively affected than males by professional boxing, and 4) extensively to hypotheses about the physiology of educational boxing as well as that of baby boxing practitioners.

Keywords

Boxing, Educational Boxing, Baby Boxing, Integrative Physiology, Musculoskeletal Physiology

1. Introduction

Contrary to other forms of boxing (Thai boxing, American boxing or French boxing), the 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 reaching their own anterior and lateral surfaces of the head, the neck, and the trunk, above an imaginary plane passing through the top of both iliac crests and parallel to the ring.

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

The review concerned here deals with the physiology of boxing practitioners. The present article is the fourth and last of four parts of the whole review. The first part of the review deals with kinanthropometric parameters, skeletal muscle recruitment, and ergometry [1]. The second part deals with boxing practice-derived systemic responses and adaptations [2]. The third part deals with dietary supplementation, weight control, recovery, and altitude [3]. As far as boxing practice is concerned, the present and last part is related to faith, life expectancy, gender, and childhood.

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

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 paper 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. Faith, Life Expectancy, Gender, and Childhood

2.1. Faith

Faith is the belief and trust in God [4].

More than one boxing practitioner has expressed his faith in a being whom people believe has created the universe and controls the world [4]. The aforementioned being is called Allah by the Muslims and God by the Christians [4]. Muhammad Ali, Trevor Berbick, Mike Tyson, Naseem Hamed, and Marco Antonio Barrera are examples of the aforementioned believers.

Controlling a boxer's physiological variables makes it possible to have control over physical, technical, tactical, and/or psychological factors that may influence boxing battle decisions (wins, losses, and draws). May praying by itself or in combination with preaching influence the reaction of Allah/God in a way that favors the victory of the boxer who has prayed over his opponent? On the side of which of the two opposing boxers is Allah/God going to be in the case that each of them has prayed asking for victory?

Let us recall two battles in which each of the concerned boxers was a believer.

2.1.1. Two Battles Opposing Boxers Believing in Allah/God

On November 22, 1986, in Las Vegas, a boxing battle took place between Trevor Berbick and Mike Tyson.

According to Xabier Azpitarte's comment [5]-[7], Trevor Berbick stated that 1) he was going to defeat Mike Tyson, and that 2) God was only on his side and could not be on the side of such a bad person as Mike Tyson. The commentator also drew attention to the red-colored cross that could be seen on the left leg of Trevor Berbick's shorts.

However, in the second round of the battle, the second of the two times Trevor Berbick was knocked down by Mike Tyson's punches, the former tried to stand up, went down, and tried to stand up once more [5]-[7]. Almost knocked out, Trevor Berbick began to sway about the ring, which made the referee take pity on Trevor Berbick and stop the battle [5]-[7].

The power and the bluntness of Mike Tyson's punches defeated Trevor Berbick in spite of the latter's faith in God.

On April 7, 2001, in Las Vegas, another boxing battle took place between Naseem Hamed and Marco Antonio Barrera.

Before that battle, Naseem Hamed was used to thanking God at the end of the battle [8]. But on April 7, 2001, 1) Islamic persons preached where and before the battle took place, 2) it could be read on Naseem Hamed's shorts the writing "Islam", Islam which is presented as a religion that permits, among other things, human beings to communicate with Allah, to know the will of Allah, and to benefit from the results of living according to Allah's will [9], and 3) before climbing up onto the ring, Naseem Hamed came from a higher altitude, while the being which is referred to as Allah/God is believed by more than one person to reside in the heaven, at an altitude higher than that of where the humans live, of where the boxing ring was situated.

As for him, Marco Antonio Barrera limited himself to making the sign of the Cross on himself and said something like the following: "During our battle, in the ring, Allah is not going to be on the side of Naseem Hamed" [8].

The result of the battle was the defeat of Naseem Hamed by Marco Antonio

Barrera.

What is suggested 1) by the defeat inflicted on the Christian Trevor Berbick by the Muslim Mike Tyson, and 2) by the defeat suffered by the Muslim Naseem Hamed in his battle against the Christian Marco Antonio Barrera?

A believer may think that Allah/God dislikes boxing practice.

As praying may be speaking to God in order to ask for help [4], praying in order to ask for victory from Allah/God may be the expression of a will, of the intention of winning over the boxer to whom one is opposed. On the other hand, the boxer's intention has been found to influence the physical factor of punching force, when a comparison has been held between the situation of maximum force production intention and the situation of maximum speed production intention [10]. One may thus expect a possible contribution of praying to the victory of a boxer over the boxer opposed to him, through the intention of winning.

One may also think that faith is only one among several components that may contribute to the total variation present in a set of data, 1) each of the components being associated with a specific source of variation, and 2) the data being the wins achieved or the losses suffered by boxing competitors.

2.1.2. Reminder

Despite the faith of each of the four concerned male boxers in Allah/God, a Christian boxer has been defeated by a Muslim boxer, while a Muslim boxer has been beaten by a Christian boxer.

2.1.3. Advice

Boxers who believe in Allah/God are advised not to rely solely on their faith but must also take into account the fact that the set of data that may influence boxing battle decisions (wins, losses, and draws) comprises known components of a physical, technical, tactical, and psychological nature.

2.2. Life Expectancy

Life expectancy is the length of time that a subject is thought to live because that seems likely [4].

Prolongation of life may derive from maintaining appropriate body fitness, using judicious regimens of exercise and weight control, prolongation taking place through a great reduction of cardiovascular disease, reduction of the number of heart attacks, brain strokes, and kidney disease [11]. Moreover, the increased mean life expectancies of world-class male athletes have been mainly explained by decreased cardiovascular mortality [12].

Is that the case also for boxing practice and life expectancy?

2.2.1. Life Expectancy as Influenced by Sport Practice, Race, and the Passing of Time

1) ***Boxers Compared with Non-Boxers***

A reference cohort selected from the Finnish Defense Forces conscription register matched on age and area of residence has been, in respect of life expectancy, compared with Finnish male world-class athletes (track and field athletics, cross-country skiing, soccer, ice hockey, basketball, boxing, wrestling, weightlifting, and shooting) [12]. When compared with that in the reference group, mean life expectancy resulted increased in world-class power sports practitioners (boxers, wrestlers, weightlifters, and throwers from field athletics) [mean life expectancies (and their 95% confidence limits): 69.9 (69.0, 70.9) years versus 71.5 (70.4, 72.2) years] [12].

Another study compared the life expectancy of non-boxers with that of boxers (not that of power sports practitioners, comprising boxers) [13]. All the concerned boxers had contested for World Championship titles from 1889 to 2019. The result, shown in **Table 2**, has been that world elite heavyweight boxers showed shorter average life expectancy when the comparison was made between white boxers and white males from the general US population, as well as between non-white boxers and black males from the general US population.

The results gathered suggest that 1) boxing practice decreases boxers' life expectancy and that 2) pooling together boxers with other power sport practitioners (wrestlers, weightlifters, and throwers from field athletics), the resulting mean life expectancy does not lose its advantage of having a value higher than that of controls' mean life expectancy, as if comparison had been held between controls' life expectancy and life expectancy of wrestlers, weightlifters, and throwers from field athletics, boxers being excluded from power sports practitioners.

Table 2. Comparison of average life expectancy between boxers and the general US population.

Calendar Year	US General Male Population		World Elite Heavyweight Boxers	
	White	Black	White	Non-white
2006	75.7 years	69.5 years	8.4 years shorter	9.7 years shorter
2017	76.1 years	71.5 years	8.8 years shorter	11.7 years shorter

a. World elite heavyweight boxers showed shorter average life expectancy when a comparison was made between white boxers and white males from the general US population, as well as between non-white boxers and black males from the general US population. b. References for the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

2) ***Boxers Compared with Other Sportspersons***

In respect of life expectancy, a comparison has been held between male practitioners of various sports who were born between 1860 and 1930 and selected from the international "hall of fame" inductees (boxing, baseball, basketball, football, ice hockey, swimming, tennis, track and field, as well as wrestling male practitioners) [14].

Similar life expectancies have been found in boxers of different weights or career records. Median life expectancy has been found to be relatively low in boxers (73.0 years), but no differences have been observed in various sports.

The median life expectancy of the samples was 76.0 years. Sports of different physiological demand were similar with respect to life expectancy.

3) ***White Boxers Compared with Non-White Boxers***

A study carried out to compare the life expectancy of white elite heavyweight boxers with that of non-white elite heavyweight boxers who had contested for World Championship titles from 1889 to 2019 showed that non-white boxers 1) died at an earlier age than white boxers (mean ± SD: 58.9 ± 14.2 years versus 67.3 ± 16.4 years, p = 0.018), and 2) showed a shorter survival [hazard ratio = 2.13 (95% confidence interval = 1.4 - 3.3)] [13].

In comparison with the respective general US population, boxing practice-induced shortening of life expectancy has resulted in more years in non-white boxers than in white boxers [13]. Please see **Table 2**.

As what has been found in boxers is identical with what has been found in the general population, here, boxers' races account for the disparity between the life expectancy of white and that of non-white boxers.

4) ***Passing of Time Influence on Boxers' Life Expectancy***

The passage of time could possibly affect life expectancy in boxers.

In fact, Silbernagl and Lang have signaled an increase in general population life expectancy over time [15].

On the other hand, comparison being held between life expectancies in 2006 and 2017, 1) in the general US population, an increase in life expectancy has been noticed, while for the same years, 2) in US boxers, an increase in life expectancy shortening has also been noticed [13]. Please see also **Table 2**.

The possibility of life expectancy alternating between increase and decrease with the passing of time, in boxers and/or in the general population, must not be excluded before submitting it to the examination of research workers.

2.2.2. Reminder

Male boxer life expectancies have shown a median value lower than that of various sportspersons including boxers, while the concerned study found no difference in life expectancy when comparisons have been made between 1) boxers of different weight records, 2) boxers of different career records, and 3) sports of different physiological demands [14].

The relatively low value for boxers may explain 1) why in another study elite heavyweight boxers have shown a mean life expectancy lower than that of the controls [13], and 2) why in a third study, compared with that of the controls, an increase in mean life expectancy of world-class power sports practitioners, boxers included, has been found [12].

Boxing practice-yielded shortening of life expectancy has been found to be of more years in non-white boxers than in white boxers.

2.2.3. Advice and Suggestions

As boxing practice shortens the life expectancy of boxers, the latters are advised to take that fact into account while planning their lives for the long term.

It is worthwhile to carry out research work in order to find out the results of comparing boxers and other power sport practitioners (wrestlers, weightlifters, and throwers from field athletics) regarding mortality due to cardiovascular disease, heart attacks, brain strokes, and kidney disease, as 1) no difference has been found in the median life expectancies of sports with different physiological demands [14]; 2) elite heavyweight boxers have shown a mean life expectancy lower than that of the controls [13]; 3) compared with that of the controls, an increase in the mean life expectancy of world-class power sport practitioners, including boxers, has been found [12]; and 4) prolongation of life may take place through the reduction of cardiovascular disease, reduction in the number of heart attacks, brain strokes, and kidney disease [11].

Research work is also worth being carried out to determine the trend of boxers' mean life expectancies over time: upward trend, downward trend, or alternation between upward and downward trends?

2.3. Gender

Gender is the fact of being male or female [4]. A female person belongs to the gender that can have babies [4], while a male person cannot have babies [4].

2.3.1. Impacts Experienced While Boxing

The authors of a study undertaken with the purpose of characterizing impact exposure during training and competition among male and female athletes participating in boxing and mixed martial arts noticed 1) that mixed martial arts athletes and boxers experienced a comparable number of impacts per practice session or competition, 2) that per athlete per sparring session, on average, men experienced a higher number of head impacts than women, and 3) that despite that disparity, there were no statistically significant differences in the linear and rotational magnitudes of impacts experienced by male and female athletes [16].

Physiological data possibly explaining the results just mentioned are displayed below.

1) ***Comparable Impact Number in Boxing and Mixed Martial Arts Practices***

As boxers and mixed martial arts athletes have experienced a comparable number of impacts per practice session or competition [16], the conclusions drawn from both kinds of athletes combined may be valid when only boxers enrolled in the concerned study are considered.

2) ***Number of Head Impacts Lower in Female than in Male Athletes***

a) Sparring Session and Head Impacts Experienced

Per athlete and per sparring session, females experienced a lower number of head impacts than male athletes [16]. One may consider two things: 1) the number of impacts, and 2) the fact that the situations opposing the athletes consisted of sparring sessions but not competitions.

b) *Reaction Time*

While boxing, athletes may either deliver or receive impacts.

Boxing practice comprises attack preparations, attacks, defenses, counterattacks, and psychological warfare. During the course of each of the 5 kinds of actions, three things happen: 1) the perception of the precursory signs of a possible imminent action from the opponent, 2) the processing of the information derived from the perception, and 3) the exploitation of what results from the processing so as to try to achieve what the boxer wants.

For instance, a boxer first notices an uncovered legal target on his opponent's organism, spontaneously uncovered or uncovered due to the boxer's attack preparation. Lastly, the boxer tries to land a fist successfully on the target. The boxer may also perceive the signs of a possible attack from his opponent and finally either avoid the impact that could derive from a successful attack from the opponent or counterattack while avoiding the impact.

The lower number of head impacts experienced by females when compared with male athletes may have resulted from landing fist velocities being lower and/or fatigue occurring earlier in females than in male athletes.

Theoretically, lower fist landing velocity as well as earlier fatigue occurrence may concern 1) the perception of precursory signs of a possible imminent action from the opponent, 2) the processing of the information derived from the perception, 3) the transmission of the processed information from the nervous system to the skeletal muscles involved in trying to achieve what is wanted by the concerned boxer, and/or 4) the skeletal muscles' performance of movements required to achieve what is wanted by the boxer.

Furthermore, it has been found that, with an increasing number of professional fights, 1) reaction time performance decreased (improved) in both female and male fighters, but 2) the improvement was slower in females than in males [17]. Hence, at any given time of the fighting career, one may expect a worse reaction time (a lower number of successfully landed fists) in female than in male fighters per time unit.

However, the concerned study [17] indicates that psychomotor speed is higher in females than in males.

Higher speed accompanied by lower reaction time performance could be due to possible nociception or pain, possibly higher in female than in male fighters.

c) *Body Composition*

Variation of fat mass and fat-free mass according to gender generates consequences regarding energy [18], consequences that could possibly explain why head impact numbers are lower in females than in males per sparring session.

- *Fat Mass and Fat-Free Mass*

Even in sportspersons, for the same body mass index (BMI), women show more fat than men, while 2) at the same mean age, women show less fat-free mass than men's [18].

- *Muscle Fibers*

Young female humans show smaller muscle fiber diameter, particularly in the upper limbs, which contributes to their throwing performance limitation [19], when compared to their male counterparts.

Moreover, after an aerobic training period, Type I and Type II muscle fiber areas generally remain smaller in women than in men, according to various authors [18], while 2) after a resistance training period, hypertrophy is much less noticeable and the increase in Type II muscle fiber area is less easy in women than in men [18].

- *Contractile Proteins*

Women show fewer contractile proteins than shown by men [18], which could contribute to the explanation of why women show maximal oxygen consumption ($\dot{V}O_2\,max$) values lower than those shown by men [18].

d) *Iron*, *Hemoglobin*, *Oxygen and Fatigue*

Physical performance limits are closely related to muscle fatigue [20].

In women, compared with men, an earlier onset of fatigue may be expected. In fact, onset of fatigue may be delayed by enhanced oxygen availability due to increased levels of hemoglobin [20]. However, the levels of iron, the levels of hemoglobin, and the oxygen-carrying capacity of blood shown by women are lower than those shown by men [18].

e) *Maximal Oxygen Consumption and Phosphocreatine*

Boxing is among the sports that require competitors to engage repeatedly in high-intensity exercise with periods of rest or low intensity between efforts. Whereas a high maximal oxygen consumption ($\dot{V}O_2\,max$) is valuable even in activities involving intermittent high-intensity contractions [21], women show $\dot{V}O_2\,max$ values lower than those of men, with the values expressed either in $l{\cdot}min^{-1}$, in $ml{\cdot}min^{-1}{\cdot}kg^{-1}$ of body mass, or in $ml{\cdot}min^{-1}{\cdot}kg^{-1}$ of fat-free mass [18]. That leads to the expectation of a lower number of punches in women than in men during periods of pugilistic activity, that is, outside of rest or low pugilistic activity periods.

f) *Strength*

For the same body mass, a young adult female human has an absolute strength that is only 60% of the values seen in a young adult male human [19], which is explained by a lower quantity of muscle in women than in men [22].

When expressed relative to body weight, the lower body strength of women is similar to that of men, while the upper body strength of women is still somewhat less [22].

g) *Velocity*

Females show physical performance ability inferior to that of males with regard to velocity [18].

h) *Power*

Sex-related differences in power output are similar to those for muscular strength [22]: the average peak muscle power of the average young adult female human is only about 70% of that attained by the average young adult male human [19].

i) *Endurance*

Females show physical performance ability inferior to that of males with regard to endurance [18].

j) *Pain*

During boxing practice, females as well as males are generally opposed to practitioners of the same gender. The number of head impacts is lower in females than in males, which may possibly also result from pain, the subjective response to nociceptive input in the brain, a response that possibly may be higher in females than in males.

3) ***Comparable Impact Magnitudes in Female and Male Athletes***

No statistically significant difference has been found between female and male athletes, concerning linear and rotational magnitudes of impacts experienced, despite the disparity in the number of head impacts, which is lower in female than in male athletes per athlete per sparring session [16].

During a sparring session, a boxer strives not to hurt his/her opponent, not landing hard punches on the latter. That may result in a decrease in punching force compared with what takes place during a competition [1] [10]. Linear and/or rotational magnitudes of impacts may show a statistically significant difference when comparing females with males in a competition situation.

2.3.2. Regional Brain Volumes and Performances

A study has investigated the relationship that links the number of professional fights with brain volumes and with cognition [17]. The study cohort consisted of males matched with females, comprised of retired as well as active competitive fighters, and was comprised of boxers, martial artists, and mixed martial artists.

As shown in **Table 3**, in both male and female fighters enrolled in the study, with an increasing number of professional fights, there has been 1) a decrease in some subcortical regional brain volumes (right hippocampus, right thalamus, left putamen, and bilateral amygdala), and 2) a decrease in reaction time performance, which has made the latter faster and thus better.

Table 3 also shows that, with an increasing number of professional fights, there have been increases in female fighters but decreases in male fighters when 1) right putamen volume and 2) verbal memory performance have been concerned.

It has also been found that, with an increasing number of professional fights, left amygdala volume has been larger and psychomotor speed higher in female fighters than in male fighters.

It is worth noting that where there have been decreases in the values shown by both male and female fighters, the relationship that has linked either regional brain volumes or cognitive and motor performance with an increasing number of professional fights has been much steeper among male than among female fighters.

Table 3. Increasing number of professional fights (independent variable) and certain dependent variables.

Dependent variables	Relationship between the independent and dependent variables		
Subcortical regional brain volumes	In male fighters	In female fighters	Steepness
Right hippocampus	↓	↓	♂ > ♀
Right thalamus	↓	↓	♂ > ♀
Left putamen	↓	↓	♂ > ♀
Bilateral amygdala	↓	↓	♂ > ♀
Right putamen	↓	↑	
Left amygdala	Smaller than		
Cognitive and motor performance	In male fighters	In female fighters	Steepness
Psychomotor speed	Poorer than		
Verbal memory performance	↓	↑	
Reaction time performance	↓ (here, faster and thus, better)	↓ (here, faster and thus, better)	♂ > ♀

a. "↓" means "decrease." b. "↑" means "increase". c. "♂ > ♀" means "much steeper among males than among female fighters." d. References for the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

Physiological data possibly explaining the results just mentioned are displayed below.

1) ***Anatomical Causing Physiological Changes***

Various causes may lead to anatomical changes in an individual, which may sometimes result in physiological changes in the concerned individual.

The number of professional fights taken part in has been shown to result in subcortical regional brain volume changes in female and male fighters, which is accompanied by changes in the fighters, of their cognitive performances as well as in their motor and psychomotor performances [17].

It does not seem unsound in some cases 1) to connect the increased volume of an anatomical structure to the stimulation of the structure; 2) to connect the decreased volume of the structure to the removal or the lesion of the anatomical structure; 3) to think that the larger the volume of the structure, the higher the effectiveness of the structure; 4) to think that the poorer the psychomotor speed, the worse it is for a fighter; and 5) to think that the faster the reaction time, the better it is for a fighter.

Compared to the right brain hemisphere, in 95% of all people, the left brain hemisphere is referred to as the 'dominant hemisphere', as in it are usually much more highly developed the functions of the speech area, the motor control area, the general interpretative (Wernicke) area, and the angular gyrus area [11]. It is thus worth carrying out research work to establish possible connections between fighters' performance changes and changes in subcortical regional brain volumes that could occur either in the left, in the right, or in both brain hemispheres .

Once the connections are established, one must remember that the steeper the relationship that links the independent variable with the dependent variable, the larger the amount by which changes in the dependent variable occur for each unit change in the independent variable (each unit change in the independent variable causes larger changes in the dependent variable) [23].

2) *Low Percentage of Boxers among the Athletes Enrolled in the Study*

The study here concerned had enrolled boxers (29.1%), martial artists (8.2%), and mixed martial artists (62.7%). The low percentage of boxers makes one wonder whether the conclusions drawn from the study are valid more for mixed martial artists than for boxers.

3) *Regional Brain Volume Changes and Cognitive as well as Motor Performance*

a) Right Hippocampus Volume Decrease

- *Verbal Memory Performance*

A decrease in verbal memory performance could be expected from hippocampal volume decreases for the following reasons.

In the absence of any lesion, the hippocampus is essential for the long-term storage of declarative memory, the memory that stores what can only be recalled consciously [24].

On the contrary, 1) hippocampal lesions may cause, in concerned people, anterograde amnesia, retrograde amnesia, or both kinds of amnesia [11]; and 2) bilateral removal of portions of the hippocampi has resulted, in a few human beings, in inability to learn, in impoverishment, or in absence of consolidation of long-term memories of the verbal or symbolic thinking [11], for instance, the memory of words.

However, the results signaled by the study here concerned [17] are concerned with the right hippocampus but not with the left hippocampus or with both hippocampi. Results concerned with the left or both hippocampi are worth knowing, taking into account the fact that in most people, the functions of the speech area, the motor control area, and other areas are usually less developed in the right brain hemisphere when compared to the left brain hemisphere, which is thus referred to as the "dominant" hemisphere [11].

In the study here concerned [17], a decrease in verbal memory performance has been shown by male fighters, whereas an increase has been shown by female fighters. The cause of the increase in verbal memory performance despite the decrease in right hippocampus volume in female fighters is possibly to be found either working on the left hippocampus and/or on another anatomical structure.

- *Reaction Time Performance*

Stimuli that cause pain may excite limbic centers of punishment, a basis on which making the decision about which of our thoughts are important enough has benefited from the participation of the hippocampi especially and, to a lesser degree, of the dorsal medial nuclei of the thalamus [11].

The hippocampus has been called upon to determine whether life-or-death importance could be attached to a given stimulus before decision-making in many lower animals [11].

It has been suggested that anxiety is driven from appropriate anatomical structures which project appropriate fibers to limbic structures such as the hippocampus, the amygdala, and the hypothalamus [25].

A decrease in the volume of either the hippocampi, the amygdala, the thalamus, or the hypothalamus thus makes one expect a decrease in the drive to anxiety, which could possibly make the fighter more likely to attack the opponent than to defend oneself. It may hence be expected from hippocampi volume decreases that there will be an increase in the attempts by the concerned fighter to attack any legal target on the opponent's organism whenever the target is uncovered. That may benefit the fighter's reaction time, and the more decreased the hippocampi volumes, the faster the reaction time, as is suggested by the study results commented on here [17]: in both female and male fighters, there have been decreases in the hippocampi volumes, being steeper in the male than in the female, a relationship that has linked the number of professional fights with reaction time performances.

- *Motor Control*

The functions of the motor control area are less developed in the right brain hemisphere than in the left brain hemisphere, the 'dominant hemisphere' [11]. A volume decrease in the right hemisphere of an anatomical structure responsible for motor control thus makes one expect a worsening of control more than a volume decrease of the structure in the left hemisphere. It may hence be expected more from the right than from the left hippocampus volume decrease, an increased availability of glucose, which would facilitate the increase in the number of attacks against the opponent. In fact, lesions of the hippocampus result in the potentiation of the stress-induced adrenocorticotropic hormone (ACTH) and glucocorticoid secretion in primates and rats [25].

b) *Right Thalamus Volume Decrease*

As the relationship that has linked right thalamus volume with an increasing number of professional fights has been much steeper among male than among female fighters, the expected changes in verbal memory performance as well as in reaction time performance are expected to occur later in the female than in the male fighters.

- *Verbal Memory Performance*

With an increasing number of professional fights, a decrease in verbal memory performance could be expected, as lesions in the thalamus have been found to cause transient disorders of comprehension and finding of words [24].

However, the expected decrease in verbal memory performance has not been shown by females (increase), the contrary of what has been noticed in male fighters enrolled in the study here commented [17]. Accompanying that is an increased right putamen volume shown by the females, the contrary (decrease) of what has been noticed in male fighters [17]. The increase in putamen volume could hence possibly explain the increased verbal memory performance shown by female fighters.

- *Reaction Time Performance*

Thalamus is a relay station for sensory inputs to the cerebral cortex [25]: when nociceptors are excited, afferent nerves synapse in the spinal cord and pass via the anterolateral tracts to the thalamus, and from there to, among others, the somatosensory cortex, the cingular gyrus, and the insular cortex [24].

Lesions to intralaminar nuclei of the thalamus result in a reduction of the level of consciousness and of the perception of pain [25].

From the pain perception level reduction in a fighter, a decrease in fear of the adversary's pain-causing attacks may result. Thus, whenever legal targets on the adversary's organism are uncovered, the fighter's attacks would increase in frequency: the fighter's reaction time performance would shorten, that is, would improve.

c) *Putamen Volume Changes*

- *Right Putamen Volume Increase and Decrease*

In the study commented on here [17], right putamen volume has increased in females, whereas the volume has increased in male fighters. That has been accompanied by an increase in verbal memory performance in female fighters but a decrease in male fighters, which suggests a direct relationship linking both right putamen volume and verbal memory performance with the increasing number of professional fights.

- *Left Putamen Volume Decrease*

As for the left putamen volume decrease, in the fighters concerned here [17], it occurred in both females and males. Being less steep among female than among male fighters, the relationship that has linked left putamen decrease with the number of professional fights the occurrence of possible changes in cognitive and/or motor performances may be expected to be delayed in females when compared with males.

d) *Amygdala Volume Changes*

- *Bilateral Amygdala Volume Decrease*

It has been found that there is a decrease in bilateral amygdala volume, with the decrease occurring later in female than in male fighters, with an increasing number of professional fights [17]. In the same fighters, it has also been found that the left amygdala volume is larger and psychomotor speed is higher in female than in male fighters [17].

When an anatomical structure is concerned, it does not seem unsound to relate, on the one hand, the large volume with the stimulation, and, on the other hand, to relate the small volume with the removal or the lesion of the anatomical structure. Thus, the decrease in the volume of the bilateral amygdala shown by both female and male fighters [17] leads one to expect in both of them a decrease in bilateral amygdala performance. However, despite the amygdala volume decrease, the remaining volume being larger in female than in male fighters [17] leads one to expect in females a decrease in amygdala performance smaller than in male fighters.

- *Verbal Memory Performance*

Amnesia has been shown after bilateral removal of the amygdala with portions of the hippocampus and temporal lobe [24]. It has also been reported that there is more rapid forgetfulness in human beings as well as in monkeys after bilateral ablation of the amygdala through destruction of the anterior parts of both temporal lobes, inside which the amygdala lie [11]. That makes one expect verbal memory performance impairment.

However, in the study here commented, impairment in verbal memory performance has been shown in males, whereas the performance increased in female fighters [17]. In the same fighters, there has also been a decrease in males but an increase in female fighters' right putamen volume [17]. The increase in right putamen volume could possibly have increased the female fighters' verbal memory performance at a level that hid the expected decrease, which was smaller than that shown by the male fighters, a decrease that could have resulted from bilateral amygdala volume decrease.

- *Reaction Time Performance*

Disinhibited behavior has resulted from bilateral removal of the amygdala with portions of the hippocampus and temporal lobe [24]. Human beings as well as monkeys become unafraid of anything after bilateral ablation of the amygdala through destruction of the anterior parts of both temporal lobes inside which the amygdala lie [11]. Moreover, if monkeys are taught that an object is associated with punishment, they lose that memory after lesions of the amygdala [25].

As in humans, bilateral lesion of the amygdala may result from trauma [25]; it may be expected that with an increasing number of professional fights, there occurs a decreasing fear of the attacks from the fighter's opponent. The decreased fear of the adversary's attacks could possibly contribute to a decrease in reaction time performance, in both female and male fighters, as observed by the study here commented [17].

As the study signals that the reaction time performance decreases less rapidly in female than in male fighters, it may be expected that, per sparring session or per fight, females perform fewer attacks than male fighters, with the same frequency, the same number, and the same duration of professional fights. What is expected may also be so as the concerned study signals, among other things, that after the bilateral amygdala volume decrease, the amygdala situated in the dominant hemisphere, the left amygdala, is larger in female fighters than in male fighters.

- *Left Amygdala Remnant Volume Larger in Females than in Males*

Increasing the number of professional fights has resulted in a volume decrease of the left amygdala as well as of the bilateral amygdala in both female and male fighters [17].

From the decrease in volume, the remaining left amygdala volume has been larger in female than in male fighters, 1) which was accompanied by a psychomotor speed higher in female than in male fighters and 2) which could contribute to the difference in psychomotor speed, according to the gender of the fighters.

In the case that a causal relationship had linked the remaining left amygdala volume being larger and the psychomotor speed being higher in female than in male fighters, the increase in speed may be expected to occur later in the females than in the males, as in the former, the relationship has been found to be less steep than in the latter's [17].

Late or early occurrence of increase in psychomotor speed, the higher the speed, the quicker the performance of either attack preparations, attacks, defenses, or counterattacks. One may thus expect, more from the female than from the male fighters, a higher number per time unit of attacks and/or other fundamentals of fighting, unless something else hides the increase in number.

2.3.3. Reminder

Female and male boxers, as well as mixed martial artists, experienced a comparable number of impacts per practice session or competition. Per sparring session, females experienced a number of head impacts lower than that of male boxers and mixed martial artists, without a difference in the linear and rotational magnitudes of impacts.

Females appear less negatively affected than male fighters, as with increasing numbers of professional fights, there have been 1) decreases in both females and males of the right hippocampus, right thalamus, left putamen, and bilateral amygdala; 2) in females compared to males, a larger left amygdala, better psychomotor speed, but a later improvement in reaction time performance; and 3) an increase in females but a decrease in males of right putamen and verbal memory performance.

2.3.4. Suggestions

It is desirable that research work be carried out, enrolling only female and male boxers; focused not only on the head but also on the body as targets; and focused separately on straight, uppercut, and hook punches as weapons; with the purpose of characterizing impact exposure not only during boxing training but also during boxing competition.

As for regional brain volume anatomical changes causing changes in cognitive, motor, and psychomotor performances, it is desirable that research work be undertaken once more, but excluding martial and mixed martial artists from female and male boxers.

2.4. Childhood

Childhood is the period of time when someone is not yet a fully grown person [4].

2.4.1. Regular Boxing Training and Oral Zinc Supplementation, Lifestyle Program, as Well as Facial Injuries

1) ***Oral Zinc Supplementation***

Regular boxing training with or without oral zinc supplementation, as well as acute boxing training, may affect, in pubescent male amateur boxers, plasma levels of calcium, copper, iron, magnesium, phosphorus, and zinc, as shown in **Table 4**.

That is the result displayed by a study that enrolled 32 healthy adolescent male amateur boxers and was aimed at assessing the effects of vigorous physical activity and zinc supplementation on element distribution in young amateur boxers [26].

However, it is impossible to assess the influence of age on plasma levels of the concerned minerals due to the lack of similar results shown by adult subjects. The aforementioned results shown by healthy adolescent male boxers have been commented on where they have been dealt with dietary supplementation (please see the third part of the present review: [3], 2.4.1. Zinc supplementation).

Table 4. Influence of zinc supplementation on plasma levels of calcium, copper, iron, magnesium, phosphorus, and zinc in pubescent amateur boxers [3].

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

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

2) ***Lifestyle Program***

In overweight Hispanic children and adolescents (6 girls and 16 boys aged 11.73 ± 1.39 years), it has been observed: 1) a significant reduction in waist circumference, body mass index (BMI%), fasting glucose, and a-motivation, as well as 2) a significant increase in both moderate and vigorous intensity physical activity, intrinsic motivation, and introjected regulation [27].

Those results are the outcome of a 12-week lifestyle program that comprised a

30-minute pediatrician appointment, 12 hours of nutrition education for guardians, and twice-a-week 60-minute sessions of moderate to vigorous intensity boxing exercise training [27].

Assessing the influence of age on those results is impossible due to the lack of similar results shown by overweight Hispanic adults.

3) *Facial Injuries*

It has been reported that facial injuries occurred in 5.3% of children younger than 18 years of age who practiced boxing and martial arts [28]. Of those facial injuries, 22% were fractures. Of the concerned fractures, 70% affected the nose, 18.3% the orbit, and 10% the mandible. The cross-sectional study from which these results were derived was concerned with the period lasting from January 1, 2010, to December 31, 2019.

Here also, assessing the influence of age on the results is not possible due to the lack of similar results shown by adults.

2.4.2. Educational Boxing

Educational boxing is a unique form of competitive boxing in which the boxer strives to increase the safety of the opponent he aims to defeat by landing, by means of fists, exclusively light touches instead of blows [29]. A light touch is a kind of blow that does not cause harm.

Educational boxing has been found to be practiced almost exclusively by children and adolescents in France [30].

During the 2003-2004 boxing season, educational boxers were less numerous than amateur boxers but became 2.6, 2.9, and 2.6 times more numerous than amateur boxers during the following three boxing seasons, respectively [30]. Professional boxers were the least numerous boxers during the concerned four boxing seasons [30].

The educational boxer is punished whenever he has landed, or only seems to be about to land, on his or her opponent a blow instead of a light touch [30].

The newcomer in educational boxing must thus perform appropriate exercises to be able to land a fast and correct blow that does not harm the opponent (a light touch delivered by means of a fist) [29].

Educational boxing skills may be taught either in the traditional way or through play.

While teaching educational boxing in the traditional way, the coach 1) teaches the pupil the stance posture, attack techniques, defense techniques, and tactics to be used to facilitate winning boxing matches, and 2) makes the pupil execute physical exercises that facilitate boxing easily, as well as exercises that permit the pupil to control emotions such as fear and anger.

Educational boxing teaching has also been approached through play by Pierre Cougoulic, Stéphane Raynaud, and Benoit Cougoulic [31]. Both play-based learning and problem-based learning are in the approach: the coach faces the pupil with difficult situations, which the latter must cope with through play movements that permit the pupil to acquire educational boxing-specific physical, technical, tactical, and psychological abilities.

1) *Hypothesis about the Performing of a Light Touch instead of a Blow*

Whereas the trend may be to attain maximal power output while landing blows to the opponent in other forms of boxing, the trend must be to use what may be referred to as the "minimal power output" while landing light touches to the opponent in educational boxing.

It is not unsound to think that, for the manifestation of the 'minimal power output', reverse occurrence of the events that lead to maximal power output may take place.

What might those possible events be?

Perception, motivation, and movement are the three principal functions performed by the lobes and areas of the cerebral cortex due to the associative relationships the lobes and areas form [25]. *Motivation for practicing educational boxing, perception of legal targets on the opponent's body, perception of the movements performed while attacking and/or defending oneself, as well as performing the movements itself, rely on the aforementioned lobes and areas of the cerebral cortex*.

A wide range of neural and muscular factors must combine optimally to produce maximal power output [32]. Certain training modes affect these components in a negative manner [32]. *Assuming that the aforementioned components are affected negatively, one may presume to have the explanation why educational boxing training progressively makes the newcomer able to land correctly and rapidly closed fists but exclusively using the least force possible.*

Supra-spinal motor areas of the central nervous system include motor areas of the cerebral cortex, the cerebellum, and various nuclei in the brain and brainstem, some of which give rise to descending tracts that affect the motoneurons directly or – more often – indirectly through interneurons [33].

Both pyramidal and extrapyramidal descending influences ultimately meet at the motoneuron to modulate its activity [25].

The pyramidal tract, or corticospinal tract, is the only pathway whose axons pass uninterrupted by any synapses from the cerebral cortex to their ultimate destinations in the spinal cord [25]. Some of the axons of the pyramidal tract originate in the primary motor cortex, whereas other axons arise outside the primary motor cortex (the area in front of the central sulcus, as well as the somatosensory cortex areas SI and SII) [25].

Extrapyramidal fibers may originate in the frontal or parietal cortex, and travel to the cerebellum, or to other major extrapyramidal sites such as the striatum, the substantia nigra, the reticular formation, the tegmental nuclei, and the red nucleus [25]. From these central structures, second-order, third-order neurons, or both, project downwards through the spinal cord in various pathways, at different levels, and give off branches that synapse with motoneurons or interneurons in the gray matter of the spinal cord [25].

Almost all the synapses used for transmission in the human central nervous system are chemical synapses, in which the first neuron secretes at its nerve ending synapse a chemical substance called "neurotransmitter", which in turn acts on receptor proteins in the membrane of the next neuron to excite the neuron, to inhibit it, or to modify its sensitivity in some other way [11]. In the central nervous system, only a few examples of gap junctions have been found [11]. The gap junctions form most electrical synapses [11].

The motoneurons are influenced by several sources, including afferents from the periphery and descending tracts from supra-spinal levels, as well as local spinal circuitry [33].

Mostly through interneurons, but also directly, central nervous system supra-spinal motor areas' descending tracts affect the motoneurons [33].

The motoneurons are responsible for the ultimate command of muscle contraction [33].

When a motor neuron fires an impulse or action potential, all of the fibers that it serves are simultaneously activated and develop force [34].

The neuromuscular junction (NMJ) is the synapse where electrical information is chemically transmitted from a branch of the motor axon to a skeletal muscle fiber, the motoneuron having its cell body in the spinal cord and its axon terminating at the motor endplate [25].

When affected by the supra-spinal motor areas of the central nervous system, the descending tracts and/or the afferents from the periphery, in the motoneurones and/or in the possibly related neurons, one may expect excitation, inhibition, and/or a modification of sensitivity. That could possibly contribute to a decrease in the force with which the educational boxer lands his/her fists on the opponent's legal targets.

Virtually all body movements involve the action of more than one muscle: 1) the agonist or prime mover, the muscle or muscle group actively causing the movement; 2) the synergist, the muscle or muscle group that assists indirectly in a movement; and 3) the antagonist, the sometimes passive (*i.e.*, not concentrically involved) muscle or muscle group located on the opposite side of the limb and that can slow down or stop the movement [35] [36]. To produce high power output, the agonists must be fully activated, the synergists must be appropriately activated, and the antagonists must be appropriately activated [32]. *Thus, in educational boxing, landing a light touch instead of a blow, i.e., using the least force possible while landing a fist to the opponent, could possibly result from incomplete activation of the agonists, inappropriate activation of the synergists, and/or inappropriate activation of the antagonists.*

When a classical transmitter has performed its job on the postsynaptic membrane, its action must be rapidly terminated [33]. For that, 1) the neurotransmitter may be inactivated by enzymatic cleavage, 2) the transmitter may be inactivated by reuptake into the synaptic terminal, or 3) the transmitter may be removed from the synaptic cleft by uptake both into the neighboring glial cells and back into the synaptic terminal [33]. That is valid both for central nervous system synapses and for the neuromuscular junctions.

As there is a special nervous circuit for every single muscle activity and movement, it is not surprising that some of the effects of training and practice modify the behavior of the central nervous system [33].

2) *Training Effect on Muscle Strength and Power*

The training effect on muscle strength may be influenced by neural adaptations as well as by adaptive changes in skeletal muscle [33].

a) Neural Factors

Positive self-talk, imagery, determination, preparatory arousal, and aggression are psychological techniques thought to increase the arousal level of the central nervous system so as to produce maximal levels of strength and power [37]. *That could possibly provide some explanation for the ability to land light touches on the opponent instead of blows. In fact, in educational boxing, the determination is to produce the lowest possible levels of strength and power while landing fists on the opponent. Furthermore, an aggressive appearance during educational boxing competition is forbidden and punished.*

Much of the improvement in strength evidenced in the first few weeks of resistance training is attributable to neural adaptations, as the brain learns how to generate more force from a given amount of contractile tissue [36]. *Appropriate exercises performed by the newcomer in educational boxing make the newcomer able to land on the opponent with fast and correct fists that do not cause harm* [29] [38]. *That could possibly reverse the aforementioned neural adaptations in educational boxing newcomers.*

Theoretically, the inability to engage the muscle maximally may derive from insufficient excitation or excessive inhibition of the motoneurones in question, resulting from supraspinal influence or reflex activity. *Supraspinal and/or reflex activity induced by educational boxing training could possibly cause insufficient excitation and/or excessive inhibition of the concerned motoneurones, thus making the concerned muscle engage as little as possible.*

Muscle force increases with increasing 1) number of motor units involved in a contraction, 2) size of the motor units, or 3) velocity of the motor units firing [36].

As the training effect on muscle strength may be influenced by the ability of the central nervous system to recruit all the motor units in the muscle maximally [33], *it may be hypothesized that educational boxing training stimulates the central nervous system to recruit the least number of motor units in the agonist muscles.*

Motor units are recruited from slow-twitch to fast-twitch types [32]. However, 1) with strength and power training, the ability to recruit the higher-threshold units is improved [32]; 2) as a result of power training, the neural system may learn to preferentially recruit the more powerful fast-twitch motor unit immediately [32]; and 3) most likely as a result of power training, fast muscles, *i.e.*, the muscles with a relatively high proportion of fast-twitch motor units, may be preferentially activated over slow muscles when high-velocity movements are attempted [32].

Most likely as a result of power training, selective activation of agonists within a muscle group is possible, whereas with strength and power training, increased activation of agonists is also possible [32]. *Maybe educational boxing training can result in decreased activation of agonist muscles involved in landing fists to the opponent*.

Proprioceptors are specialized sensory receptors that provide the conscious and the subconscious parts of the central nervous system with information needed to maintain muscle tone and perform complex coordinate movements [34]. Golgi tendon organs are proprioceptors; neural input from them inhibits muscle activation, whereas muscle spindles are proprioceptors that facilitate activation of the muscle [34]. The Golgi tendon organ's inhibitory process is thought to provide a mechanism that protects against the development of excessive tension [34]. *Golgi tendon organs could thus play a crucial role when an educational boxer voluntarily lands a light touch instead of a blow*.

b) *Intramuscular Factors*

Maximum contraction velocity and power output of fast-twitch muscle fibers are approximately fourfold those of slow-twitch types [32]. Considerable shifts between fiber characteristics are possible [32]. *Educational boxing training could possibly yield a shift such as the conversion of slow-twitch muscle fibers into fast-twitch muscle fibers*, *which could result in the educational boxer's ability to land light touches in place of blows*. *In fact*, *loss of force may derive from the high intrinsic velocity of shortening* [33].

All else being equal, the force a muscle can exert is related to its cross-sectional area [33] [36]. *One may hence wonder whether educational boxing training could result in a decrease of engaged muscles' cross-sectional areas*, *which could render difficult the conversion of the educational boxer into a practitioner of other forms of competition boxing*.

Training may affect the angle of pennation, the angle between the muscle fibers and an imaginary line between the muscle's origin and insertion, which may affect strength and velocity of shortening, being either advantageous or disadvantageous, as the case may be [33] [36]. *One may imagine educational boxing training making or keeping adapted to the educational boxing practice the angle of pennation of the concerned muscles*, *which could also render difficult the conversion of the educational boxer into a practitioner of other forms of competition boxing*.

The muscle can generate the greatest force at its resting length: when the muscle is stretched much beyond its resting length, as well as when the muscle contracts too much below its resting length, the muscle cannot generate as much force as it can at its resting length [36]. *As an educational boxer strives to land light touches on the opponent instead of blows*, *stretching the concerned muscles beyond their resting levels or contracting the muscles much below their resting levels may possibly be helpful to the boxer*.

Loss of force may derive from a high intrinsic velocity of shortening [33]. *That is not in contradiction to what resulted from a study that showed that punching* *force is higher when the intention is maximum force production than when the intention is maximum speed production* [1] [10]. *Possibly, the intention of producing the least force possible, coupled with high intrinsic velocity of the concerned muscles' shortening where the latter exists, may help educational boxers in landing light touches in place of blows* .

Strength-to-mass ratio 1) is the ratio of the strength of the muscles involved in the movement to the mass of the body parts being accelerated; 2) directly reflects an athlete's ability to accelerate his or her body; 3) is reduced when, after training, the percentage increase in force capability is lower than that of body mass increase [36]. *Most educational boxing practitioners are children, i.e., not yet fully grown persons: they are still growing. The mass of the body parts those children accelerate during educational boxing movements is thus expected to be increasing, while educational boxing training causes the children to use the least strength possible so as to produce what may be referred to as "the minimal power output". It may hence also be expected that a beneficial educational boxing training-produced decrease in the strength-to-mass ratio of the concerned practitioners occurs.*

2) ***Concerns about Conversion of the Educational Boxer into other Forms of Boxing Practitioner***

Learning brings about structural modifications in the synapses, as well as making unused synapses fade away [39]. *Educational boxing training and practice may possibly cause synaptic modifications that favor landing light touches over landing blows. Possibly, the same training and practice could also cause the synapses responsible for landing blows to fade away.*

Up-regulation and down-regulation of receptors, as well as other control mechanisms for adjusting synaptic sensitivity, continually adjust the sensitivity in each circuit to almost the exact level required for proper function [11]. The automatic controls normally readjust the sensitivities of the circuits back to controllable ranges of reactivity any time the circuits begin to be either too active or too depressed [11]. *Continual adjustments proper to landing light touches instead of blows may possibly create a habit difficult to change: "old habits die hard".*

As there is a special nervous circuit for every single muscle activity and movement, it is not surprising that some of the effects of training and practice modify the behavior of the central nervous system [33]. *Central nervous system behavior could thus possibly be modified due to the effects of training and practice during which exclusively light touches are landed instead of blows.*

Learning and memorization cause modifications in human behavior [39]. Procedural memory, one of the four types of implicit memory, includes skills and habits, which, once acquired, become unconscious and automatic [40]. Once a skill is acquired, it is hard to get rid of it [41]. *Training to land light touches instead of blows may possibly make the boxer more prone to land light touches than to land blows. Moreover, the educational boxing practitioner could possibly have difficulties in voluntarily beginning to land blows, especially hard blows, when he has been for a long time accustomed to landing light touches instead of blows.*

2.4.3. Baby Boxing

Baby boxing is a non-sporting activity that has been created by Cougoulic P., Raymond S., and Cougoulic B. to meet the wishes of some parents who expected a positive influence of boxing practice on their children's development [31]. It is actually a play for persons aged 5 and above, although the players don boxing gloves [31]. Cougoulic *et al.* expect positive psychological as well as physical development in "those playful children wearing gloves, hitting devices with all their strength…" [31].

1) ***Baby Boxing Practice***

a) Baby Boxing Creation

Baby boxing has been created in France [31], where educational boxing has also been created.

Children may be allowed to practice baby boxing when aged at least 5, that is, when they are not old enough either to be license owners or to compete in Championships of the French Federation of Boxing [31].

It is only for educational boxing practice that the French Federation of Boxing allows 1) license ownership to children aged at least 12 and 2) competition in federal championships to children aged at least 13 [42].

b) Wearing Gloves

Gloves are donned by practitioners of educational boxing as well as by those of baby boxing [31].

c) Exchanges

Exchange plays may be present in both baby boxing and educational boxing [31].

- *Attacking Weapons*

In baby boxing, as well as in educational boxing, the fists of the child must not harm his/her opponent [31]: blows are forbidden.

In baby boxing, the child puts his/her fist onto a human or a non-human surface, while in educational boxing, the child uses his fist to land light touches on his/her opponent's regular target surface [31]. The opponent is a human.

- *Targets*

To put one's fist onto the opponent's face is generally avoided in baby boxing, while in educational boxing, light touches are allowed to be landed with the regular blowing surface on the whole regular target area [31]. The latter area also comprises the face.

- *Attack and Defense Movements*

The ludic activity named "baby boxing" excludes teaching techniques of both attack and defense: the child spontaneously puts his fist onto a target [31].

In the sporting activity named "educational boxing", although avoiding by spontaneous movements to be touched by the opponent and landing spontaneously light touches on the opponent's regular target areas has been introduced by the creators of the ludic baby boxing, teaching in the traditional way techniques of attack and those of defense to educational boxers is not excluded [31].

- *Imitation of Amateur and Professional Boxers*

When baby boxers are invited to imitate amateur and professional boxers, precautions are taken to separate each practitioner from his or her opponent by a distance of three meters [31]. Those precautions are not taken in educational boxing.

d) *Public Demonstrations*

In baby boxing, public demonstrations replace competitions that take place in educational boxing [31].

e) *Baby Boxing Appearance*

Referring to baby boxing practitioners, baby boxing creators (Pierre Cougoulic, Stéphane Raynaud, and Benoit Cougoulic) speak of "those playful children wearing gloves, hitting devices with all their strength, huddling together, running and jumping, having fun touching each other … have a positive influence as ambassadors of our sport" [31].

2) ***Hypothesis about the Physiology of the Baby Boxing Player***

a) *Baby Boxers Clothing*

Baby boxers' clothing is comprised of a pair of ankle boots, a pair of shorts, a T-shirt, a pair of boxing gloves, and a head-guard.

In children ranging in age from 5 to 7, 1) baby boxing has been practiced during the sporting season 2004-2005 [31] [43]; 2) compared with those in children aged 8 and over, in the baby boxer, a) the body surface area covered with the head-guard is relatively bigger (the head length and volume are proportionately more considerable [41] [44]); b) the body surface area covered with the boxing gloves is also relatively bigger (limbs, including upper limbs, are relatively shorter [44]); c) the body surface area covered with the head-guard and the boxing gloves is thus relatively bigger; and d) the body surface area not covered with the boxing gloves and the head-guard is thus relatively smaller and, moreover; 3) the pair of ankle boots, the pair of shorts, and the T-shirt increase the covered body surface area in the baby boxer here concerned with.

One may wonder whether or not 1) the baby boxer is subjected to intense physical activity, 2) in the baby boxer, thermoregulation is influenced by the size of the quotient of the covered body surface area over the total body surface area (the non-covered plus the area covered by the baby boxing clothing), 3) growth of the baby boxers is influenced by the weight of the baby boxing gloves and head-guard, and 4) the future behavior of former baby boxers in society is influenced by the nature of the boxing gloves, gloves utilized during amateur and professional boxing, activities from which may result in physical harm.

b) *Intense Physical Activity Performed by Baby Boxers*

One is inclined to assume that baby boxing subjects its practitioners, all under the age of 8, to an intense physical activity as 1) the periods of practice are not determined, as 2) the physical activity includes the free use of all their strength, and as 3) part of the practitioners' clothing is possibly too heavy for them (ankle boots they must lift while moving their feet, boxing gloves they wear on their hands, and head-guards they wear on their heads).

c) Heat Exchange in Baby Boxers

- *Heat Exchange through Skin*

To protect itself against excessively high temperatures, the human body causes the skin to intervene in most of the body heat loss through the mechanisms of radiation, conduction, convection, and sweat evaporation [41].

- *Heat Exchange in Children*
    - *Radiation, Conduction, Evaporation*

As the ratio of body surface area to weight ($m^2 \cdot kg^{-1}$) increases with the decrease in height, in the living body, heat exchanges through radiation and conduction are higher in the child when they are related to weight ($kcal \cdot min^{-1} \cdot kg^{-1}$ or $kJ \cdot min^{-1} \cdot kg^{-1}$) [45].

Evaporation of sweat is the chief method of excess heat dissipation during exercise [19].

- - *Hypothermia, Hypothermia*

If the ambient temperature is too hot or too cold, the risk of hyperthermia or hypothermia is higher in the child than in the adult [45].

Taking into account the particularities of heat exchange through radiation, conduction, and sweat evaporation in the child, 1) one may consider it to be normal for a child to adapt thermally to long-lasting exercise in a neutral ambient temperature, and 2) one must particularly take care when the child practices exercise in hot or cold ambient temperatures [45].

- *Body Heat Production, Body Heat Loss, Body Heat Gain, Clothing*
    - *Body Heat Production, Body Heat Loss, Body Heat Gain*

If not balanced by a correspondingly high rate of heat loss, an increase in the rate of metabolic heat production will cause a rise in body temperature [46].

Depending on the relative temperature of the skin and the environment, radiation, conduction, and convection may produce either body heat loss or body heat gain [46].

Evaporation of sweat always causes body heat loss [46].

Severe physical effort increases heat production [47]. At high rates of heat production, radiation, conduction, and convection become unable to prevent the rise in body temperature because they are unable to transfer sufficient heat from the body to the environment [46], 1) which contributes to the explanation of why core temperature increases when physical effort is maximal or intense and prolonged [19], and 2) which makes necessary body heat loss through sweat evaporation [48].

If ambient temperature is high, 1) body heat gain from the environment may take place through radiation, conduction, and convection [46] [48], while 2) body heat loss through radiation and conduction from the body to the environment will decrease [46] [48], the major avenue of heat loss thus becoming the evaporation of sweat secreted onto the skin surface.

During severe physical effort and/or in a hot environment, the thermoregulatory mechanisms of the organism are overtaxed and hyperthermia results [47].

○ *Clothing*

The effect of clothing on conductive heat loss is that the rate of heat loss from the body by conduction and convection is greatly decreased as clothing entraps air next to the skin in the weave of the cloth, thereby increasing the thickness of the so-called *private zone* of air adjacent to the skin and also decreasing the flow of convective air currents [11].

The effectiveness of clothing in maintaining body temperature is almost completely lost when the clothing becomes wet because the high conductivity of water increases the rate of heat transmission through cloth 20-fold or more [11].

- *Heat Exchange in Baby Boxers*

A possible severe physical effort may take place in those boxing players aged 5 to 7, as both 1) they wear boxing gloves as well as head-guards possibly too heavy for children of their ages, and 2) it has been seen in them "playful children wearing gloves, hitting devices with all their strength [31]".

Moreover, as aforementioned, the body surface area that permits body heat loss through radiation, conduction, convection, and sweat evaporation is smaller in them than in boxers aged 8 and over because it is covered with boxing clothing (boxing gloves, head-guards, …).

Taking into account what was aforementioned, is it unsound to fear the occurrence of hyperthermia or hypothermia? Is it unsound to fear hyperthermia if the external layers of boxing gloves and head-guards are watertight, but hypothermia in the case that boxing gloves and head-guards are permeable? Is it unsound to fear hyperthermia resulting from impaired body heat loss but hypothermia resulting from excessive body heat loss?

d) *Baby Boxers' Growth*

- *Growth Hormone Effects*

Exercise is among the factors that are known to stimulate growth hormone secretion [11]: during exercise, plasma growth hormone concentration is increased [33].

Growth hormone directly activates the production of somatomedins [18] (also called "insulin-like growth factors"), somatomedins that have the potent effect of increasing all aspects of bone growth [11].

Bones thicken when subjected to heavy loads [11]. Continual physical stress stimulates osteoblastic deposition and calcification of bone [11]. Bone is deposited in proportion to the compressional load that the bone must carry; for instance, the bones of athletes become considerably heavier than those of non-athletes [11]. Sporting practice improves bone density [18].

Growth hormone stimulates cartilage growth and bone growth [11], while somatomedins production facilitates long bones growth and thus stature development [18]: the whole skeleton's growth benefits from growth hormone secretion [48].

Growth hormone stimulates muscle growth [18] and muscle mass development [18], while it has been observed that after training, better muscle mass development occurs in the child [18].

Growth hormone promotes increased sizes of the cells and increased mitosis, with the development of greater numbers of cells and specific differentiation of certain types of cells, such as bone growth cells and early muscle cells [11]. It also causes the growth of almost all tissues of the body that are capable of growing [11].

Growth hormone secretion promotes protein synthesis (anabolic action) [48].

It has been observed that after training, a decrease in body fat percentage occurs in the child [18].

As aforementioned, growth hormone directly activates the production of somatomedins [18], while somatomedins production facilitates stature development [18].

If child growth may benefit from growth hormone secretion, especially growth hormone secretion stimulated by training, however, attention has been drawn to physical and psychological damages due to excessive training in the growing child [18].

It is worth carrying out research work to determine the recommended number of play minutes in baby boxing per day, per week, and per sporting season.

- *Exercise-derived Acidosis*

Acidosis refers to a reduction in arterial blood pH below 7.35 [33].

An increase in glycolytic metabolism, during exercise of intensity higher than 60% - 70% of $\dot{V}O_2\max$, causes an intramuscular increase in protons, part of which binds with muscle buffer systems, whereas the remainder of H^+ ions is transferred into the capillaries via lactate transporters [18]. In the muscle compartment as well as in the blood compartment, pH decreases and a metabolic acidosis is the result [18].

- *Acidosis-derived Damages*

Cellular acidosis inhibits cell division and favors apoptotic cell death [49].

Prolonged acidosis promotes bone demineralization [49]. The explanation may be as follows.

As acidosis causes phosphaturia [48], hypophosphatemia may be expected. Moreover, hypophosphatemia may cause Ca^{2+} ion liberation from the bones and impair the deposition of Ca^{2+}-phosphate in the tissues [48]. That could possibly thin the bones. Additionally, acidosis increases free ionized Ca^{2+} ions filtered out by the kidneys through the decrease in binding of serum calcium with serum proteins [48]. That makes one expect hypocalcemia if Ca^{2+} ions liberated from the bones are increased, if Ca^{2+}-phosphate deposition in the tissues is impaired, and if free Ca^{2+} ions filtered out by the kidneys are increased.

Hypophosphatemia and expected hypocalcemia could possibly impair the attainment of the ideal solubility product for bone calcification. In fact, in the living organism, calcium phosphate salts are deposited, if the solubility product exceeds a certain value, mainly in the bones and sometimes also in other organs [48].

- *Buffering Power over Acidity*

The extent of metabolic acidosis depends, among other factors, on the blood's buffering power [49].

If at rest, children's intramuscular pH is not different from that of adults, during high-intensity exercises, muscular acidosis is less significant in the young child sport practitioner than in the adult [18].

Measured after maximal effort tests, low blood lactate concentration values have been observed in the child: between 5 and 25 years of age, for instance, blood lactate concentration values have increased with age [45], which suggests a possible decrease in the acidity buffering power with age.

During repeated exercises at submaximal intensity, children (boys aged ± 9) adjust the acid-base balance in the blood better than young adults (± 20) [18].

What is aforementioned suggests that the child could possibly show a buffering power more efficient than that of an adult. The existence of a better buffering power in the child could be explained partly or completely by the fact that the child shows a respiratory frequency that decreases with age while the respiratory system is a contributing factor in the prevention of acidosis.

In fact, 1) children about 5 years of age may have a respiratory frequency of about 70 at maximal exercise, 12-year-old children about 55, and 25-year-old individuals 40 to 45 [33]; whereas 2) the respiratory system a) acts within a few minutes to eliminate carbon dioxide and, therefore, carbonic acid from the body, as well as b) is one of the three primary systems that regulate the H^+ ion concentrations in the body fluids to prevent acidosis [11].

- *Suggestions*

In baby boxing, the play possibly does not cause an acidosis as high as that caused in educational, amateur, or professional boxing activities.

Research work must thus be carried out to determine the recommended number of play minutes in baby boxing per day, per week, and per sporting season, with the aim of preventing an acidosis too high for the baby boxers.

In the case that the boxing gloves could be too heavy, it is worthwhile either to prohibit their utilization or to adapt them for the boxing players here concerned, aged between 5 and 7, in whom an acidosis induced by too heavy boxing gloves must be prevented.

2.4.4. Antisocial Involvement by Former Educational Boxers and Former Baby Boxers

While creating baby boxing, Cougoulic P., Raynaud S., and Cougoulic B. expected positive psychological as well as physical development in "those playful children wearing gloves, hitting devices with all their strength…" [31].

Positive physical development could possibly result from educational boxing activities and from baby boxing activities such as hitting devices with all their strength. But, can a positive psychological development also be expected from educational boxing activities and from baby boxing activities?

On the one hand, like boxers, educational boxers as well as baby boxing players wear boxing gloves. On the other hand, boxing is among the sports that have been said to lead to an increase or enhancement of antisocial involvement in the form of elevated levels of violent as well as non-violent antisocial behavior outside sports [50].

Here appears the need to know whether antisocial involvement is prevented or enhanced when boxing gloves 1) are worn to play boxing at the early ages of 5 to 7 years or 2) are donned to practice educational boxing in strict respect for the latter form of boxing rules.

The need is to know 1) whether baby boxers may continue playing while wearing boxing gloves, 2) the recommended number of boxing play minutes per day, per week, and per sporting season, as well as 3) whether boxing practice may lead to future antisocial involvement by former educational boxers and former baby boxers.

2.4.5. Future of Former Educational Boxers and Former Baby Boxers

One may wonder whether playing baby boxing has an influence or not on the future sporting practice of educational boxing, amateur boxing, or professional boxing.

The influence may manifest itself if attacking weapons as well as targets are concerned. In fact, in baby boxing, the hand may be put onto any surface or pointed at a distant opponent, whereas in educational boxing, amateur boxing, and professional boxing, the fist (tightly closed hand with the fingers curled in towards the palm) is landed on a living opponent's legal surface targets. The fist must be landed exclusively as a light touch in educational boxing, while it is allowed to land the fist as a hard blow in amateur boxing and professional boxing. Moreover, in baby boxing, the face is excluded from whereas it is included in the regular target areas in educational, amateur, and professional boxing.

One may thus wonder whether, due to neural adaptation, 1) the former educational boxers are going to be unable to land hard blows because they are accustomed to landing light touches, and 2) the former baby boxers are going to continue excluding the face as a legal target area because they are accustomed to it.

2.4.6. Reminder

1) *During Educational Boxing Training and Practice*

a) Educational Boxing

Educational boxing is a unique form of competitive boxing in which the boxer strives to increase the safety of the opponent he aims to defeat by landing exclusively light touches, instead of blows, on the latter by means of fists. A light touch seems similar to a blow, but it must not cause harm. To be able to land a light touch, one requires preparatory training.

Educational boxing training could possibly affect, in a negative manner, the range of neural and muscular factors that must combine optimally to produce maximal power output.

Not yet fully grown, that is, still growing, educational boxers may possibly benefit from their decreasing strength-to-mass ratio, which makes them able to use their 'minimal power output' so as to land light touches instead of blows to their opponents.

b) *Neural Factors*

Motivation for practicing educational boxing, keeping in mind the duty that the light touch must not harm and the fact that even an aggressive seeming is forbidden and punished, intention of producing the least force possible, perception of legal targets on the opponent's body, perception of the movements performed while attacking and/or defending oneself, as well as voluntarily performing the movements itself, possibly rely on the lobes and areas of the cerebral cortex due to the associative relationships the lobes and areas form.

Educational boxing training and practice, during which exclusively light touches are landed instead of blows, could possibly modify central nervous system behavior by reversing the neural adaptation that ordinarily contributes to the improvement in strength evidenced in the first weeks of resistance training. One of the results could be a possible action of the supra-spinal motor areas of the central nervous system, an action that could affect the descending tracts and/or the afferents from the periphery, with the possible resulting inhibition of the sensitivity in the motoneurons and/or in the possible related neurons.

c) *Synaptic Factors*

Educational boxing training and practice may possibly 1) cause synaptic modifications that favor landing light touches over landing blows and 2) make the synapses responsible for landing blows fade away.

Supra-spinal and/or reflex activity educational boxing training-induced could possibly cause insufficient excitation and/or excessive inhibition of the concerned motoneurones, thus making the concerned muscles engage the least possible.

Educational boxing training could possibly stimulate the central nervous system to recruit the least number of motor units in the agonist muscles.

d) *Muscular Factors*

Golgi tendon organs could play a crucial role when an educational boxer voluntarily lands a light touch instead of a blow.

Training could possibly make or keep adapted to the educational boxing practice the angle of pennation of the concerned muscles.

Training could possibly yield the conversion of slow-twitch muscle fibers into fast-twitch muscle fibers, the resulting increase in intrinsic velocity of shortening thus causing a loss of force and making the educational boxer able to land light touches instead of blows.

The ability of the educational boxer to land light touches to the opponent instead of blows could possibly benefit from stretching the concerned muscles beyond their resting levels or from contracting those muscles much below their resting levels.

The ability to land light touches could also possibly benefit from incomplete activation of the concerned agonist muscles, from inappropriate activation of the concerned synergist muscles, and/or from inappropriate activation of the concerned antagonist muscles.

2) *After Educational Boxing Training and Practice*

a) Educational Boxing

Due to the educational boxing training to land light touches instead of blows, the boxer possibly 1) may become more prone to land light touches than to land blows and 2) may have difficulties in voluntarily beginning to land blows, especially hard blows, when he has been for a long time accustomed to landing light touches instead of blows.

b) Neural Factors

Central nervous system behavior could possibly be modified due to the effect of educational boxing training and practice, during which exclusively light touches are landed instead of blows.

c) Muscular Factors

Educational boxing training and practice could possibly render difficult the conversion of the educational boxer into a practitioner of other forms of competition boxing, as they may possibly result in a decrease of engaged muscles' cross-sectional areas and decreased activation of agonist muscles involved in landing fists to the opponent.

3) *During Baby Boxing Play*

One is inclined to assume that baby boxing subjects its practitioners to intense physical activity that may result in an increase in core temperature. Baby boxing also raises concerns about the occurrence of hyperthermia if the external layers of boxing gloves and head-guards are watertight, but hypothermia if they are permeable.

Stimulation of child growth resulting from an increase in growth hormone secretion could be counterbalanced by impairment of growth due to acidosis, both factors being exercise-induced. However, stimulation of child growth seems more probable than its impairment, thanks to the child's acidity buffering power, which is possibly more efficient than that of the adult.

4) *After Educational Boxing and Baby Boxing Activities*

While boxing has been said to lead to an increase or enhancement of antisocial involvement, educational boxers and baby boxers wear gloves as do practitioners of other forms of boxing before touching or hitting their opponents. Does the increase or enhancement of antisocial involvement remain valid for educational and baby boxing?

2.4.7. Suggestions

Hyperthermia, hypothermia, acidosis and antisocial involvement prevention-aimed research work is worth carrying out 1) to determine the duration and frequency of baby training sessions, 2) to decide whether boxing gloves should be prohibited or adapted for baby boxers, 3) to know whether baby boxing and educational boxing activities may impair the future practice of other forms of boxing, 4) to know whether baby boxing activities may impair the future practice of any of the remaining forms of boxing, and 5) to know whether or not boxing gloves must be worn by baby boxing players or during educational boxing activities.

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Conflicts of Interest

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

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