Université de Montréal

Metabolic requirements of boxing exercises

par

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RÉSUMÉ

Face aux données conflictuelles de la littérature sur le VO_2 requis d'exercices de boxe (sparring, palettes de frappe et sac de frappe), surtout pour le "vrai" sparring avec coups de poings au visage, une nouvelle méthode basée sur une mesure de VO_2 "post-exercice" fut développée, validée (Annexe 1) et utilisée pour ré-évaluer le coût énergétique de ces exercices de boxe.

Neufs boxeurs mâles expérimentés, de 22.0±3.5 ans et 71.4±10.9 kg avec un VO_2pic de 62.2±4.1 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ (moyenne ± écart type) furent mesurés lors 1) d'un test progressif maximal sur tapis roulant en laboratoire 2) d'un entrainement standardisé de boxe en gymnase et 3) d'exercices de boxe standardisés en laboratoire.

Des VO_2 requis de 43.4±5.9, 41.1±5.1, 24.7±6.1, 30.4±5.8 et 38.3±6.5 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, respectivement obtenues pour le sparring, les palettes de frappe et le sac de frappe à 60, 120 et 180 $coup{\cdot}min^{-1}$, situe l'intensité de ces exercices autour de ~70 %VO_2pic.

Mots clés: Sports de combat, Demande physiologique, Fréquence cardiaque, Lactate, EPE, Méthodologie.

ABSTRACT

In view of contradictory data in the literature on VO_2 requirements of boxing exercises (sparring, pad work, punching bag), particularly for “true” sparring with punches to the face, a new method based on “post-exercise” VO_2 measurements was developed, validated (Annex 1) and used to reassess the energy cost of these boxing exercises.

Nine experienced male boxers of 22.0±3.5 years old and 71.4±10.9 kg with a VO_2peak of 62.2±4.1 $ml \cdot kg^{-1} \cdot min^{-1}$ (mean ± standard deviation) were measured during 1) a maximal multistage treadmill test in the laboratory 2) a standardized boxing training in the gymnasium and 3) standardized boxing exercises in the laboratory.

VO_2 requirements of 43.4±5.9, 41.1±5.1, 24.7±6.1, 30.4±5.8 and 38.3±6.5 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively obtained for sparring, pad work and punching bag at 60, 120 and 180 $b \cdot min^{-1}$, situate the intensity of those exercises around ~70 %VO_2peak.

Key Words: Combat sports, Physiological demand, Heart rate, Lactate, RPE, Methodology.

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LIST OF ABBREVIATIONS

BAG	Punching bag
$b \cdot min^{-1}$	Beat per minute
HR	Heart rate
HRmax	Maximal heart rate
%HRmax	Percentage of maximal heart rate
[LA]	Blood lactate concentration
[LA]max	Maximal blood lactate concentration
METs	Metabolic equivalent
PAD	Pad Work
n.s.	Not significant
RPE	Rated perceived exertion
RPEmax	Maximal rated perceived exertion
SPA	Sparring
VO_2	Oxygen uptake
VO_2max	Maximal oxygen uptake
$\%VO_2max$	Percentage of maximal oxygen uptake
VO_2peak	Peak of oxygen uptake
$\%VO_2peak$	Percentage of peak oxygen uptake

DEDICATION

I wish to dedicate this master's thesis to my mother Chantal Arseneau-Frenette, my father Alyre Arseneau and my grandfather Wilfred Arseneau (1925-2005).

Fighting to make you proud…

ACKNOWLEDGEMENTS

The processes that led me to complete a master's degree and to accumulate a few amateur boxing fights, have had some similarities. Both started as simple thoughts, that I decided to take a chance at, that became a working progress, that got concretized as specific objectives that were a part of my day-to-day life, that eventually got combined together and resulted as a passion and some sort of a career path. Throughout their progression, both have required hard work, dedication and sacrifices. Many challenges have appeared, some harder than others, but by fighting through them I grew to become a better version of myself. However, none of that could have been achieved alone. Along the way I have been fortunate to obtain support from many people including family, friends, school colleagues and team members. Now that the final bell of the current challenge as rung, I stand proud of what I have accomplished, because I remember how it all started, where I come from and I know that I gave it my best efforts to make it here. Before moving on to the next challenge, I wish to take this opportunity to reminisce and to genuinely thank everybody that helped me directly or indirectly throughout these life defining adventures. More precisely, as a proof of my appreciation I wish to thank the following people…

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GENERAL INTRODUCTION

The purpose of this master's thesis was to quantify the aerobic fitness of boxers and the metabolic requirements of boxing exercises, through two distinct parts: I) a literature review and II) an experimental study.

Part I displays interesting particularities concerning literature on boxing (Section 1), introduces boxing with a description of the sport (Section 2) and describes results from different methodologies and techniques used to measure the aerobic fitness of boxers (Section 3) and the metabolic requirements of various boxing exercises such as sparring, pad work and punching bag (Section 4). This review of literature, has allowed the discovery of several studies from many different sources with numerous methodological shortcomings. More often than not, these studies were limited to the study of a single boxing exercise and none really measured the oxygen uptake (VO_2) of "true" sparring, i.e., with punches to the face and without any motion hindrance due to the measuring apparatus.

Part II was done to measure and compare the VO_2, heart rate (HR), blood lactate concentration [LA], rated perceived exertion (RPE) and punching frequency of sparring, pad work and punching bag (no [LA] measures in that condition). In addition, the aerobic fitness of boxers (VO_2peak, HRmax, [LA]max and RPEmax), was also measured in order to express the results in percentage of maximal values. Indirectly, the aerobic fitness of boxers is a witness of the metabolic requirements of that type of sport. However, since it was not possible to measure the VO_2 of "true" sparring with a collecting gas valve in the face, we developed and validated a new method to measure VO_2 of "true" sparring based on "post-exercise" measurements (Annex 1). Thus, because those measures were obtained in the LAB, certain measures (HR, [LA], RPE and punching frequency) were also collected in the GYM to see if the results were comparable in order to assess the realism of LAB simulated exercises. More precisely, the experimental study protocol consists of the three subsequent testing sessions: 1) maximal treadmill test in the LAB 2) standardized boxing training of sparring and free punching bag in the GYM and 3) standardized boxing exercises of sparring, pad work and cadence controlled punching bag in the LAB. The specific timing of the metabolic measures is described in the study. The validation study (Annex 1) was done with a separate group of subjects on a separate occasion.

PART I: LITERATURE REVIEW

Aerobic fitness of boxers and metabolic requirements of boxing exercises – A review

1.0 INTRODUCTION

Many aspects need to be considered when preparing a boxer for a competition. One that is universally regarded as important in boxing is the "cardio" in allusion to the aerobic fitness. In order to properly train a boxer and to optimize the benefits of aerobic training, a good scientific understanding of the aerobic fitness of boxers and the metabolic requirements of boxing exercises is thus necessary. Unfortunately, the few studies available on those subjects (57) are often published in journals that are difficult to find, are written in different languages (English, French, Chinese, Japanese, Russian, German, Romanian, Czech and Turkish) and used inaccurate methodologies (number and type of subjects, testing protocols, ergometers, materials used…). In an attempt to clarify those subjects and to create a new benchmark in literature on boxing, best efforts were made to provide proper interpretations of all available studies and to retain only the data that appears pertinent for our analyses. For example, we occasionally found data that were published more than once (17,18,19,73,74) and we had to delete some of those from our computations and some articles reported the average of total daily energy expenditure of boxers (43,54), but were excluded since those results are too vague and cannot fit into a specific exercise category.

Even though boxing is a popular sport around the world, to our knowledge, no extensive review paper has been conducted on aerobic fitness of boxers or metabolic requirements of boxing exercises. Thus, the purpose of this literature review will be to describe the aerobic fitness of boxers (Section 3) and the metabolic requirements of various boxing exercises (Section 4) such as sparring, pad work and punching bag. But first, it is necessary to give a brief overview of the sport of boxing and to describe some of its rules and regulations (Section 2) to better understand some of its particularities. Consequently, this review might help scientists, coaches and athletes in better understanding those subjects and in their preparation of aerobic training programs designed to improve performance in boxing.

2.0 SPORT DESCRIPTION

This section, will successively describe the sport of boxing (Section 2.1), the classification of age, number and duration of rounds (Section 2.2), the weight categories (Section 2.3), the relation between training and competition (Section 2.4), the types of stances and punches (Section 2.5) and the competition uniform and equipment worn by boxers (Section 2.6). Furthermore, when possible some comparisons will be made between amateur and professional boxing.

2.1 Boxing

English boxing or pugilism, commonly called boxing, should not be confused with French Boxing, Kick boxing, Thai boxing or any other fighting sports that may permit the use of feet, knees or elbows to strike. This review is limited to conventional boxing, which at its simplest form is the sport that consists of stand-up fist fighting. Still occasionally called the “noble art”, anciently pugilists would fight naked and be a part of the King’s festivities. Boxing is one of the oldest sports to exist today and the first proofs of existence were found in Egypt during the years 3000 BC (38). The initial forms of boxing where usually unregulated and much more dangerous. Even though the sport as evolved in many ways, boxing remains a combat sport and some risks are still present. But, in order to legalize and legitimize boxing as a sport, many rules and regulations have been created and enforced to protect both the boxers and the continuity of the sport. Through time, the rules and regulations have often changed, however, this section will solely describe the current versions being applied or described by some of the major associations or sources in amateur and professional boxing (39,40,41,42,87,89,90,91,92,93). But, since literature focuses almost exclusively on amateur boxing, this review will also focus on amateur boxing and therefore the description provided in this section for professional boxing will serve mostly as an information and comparison standpoint.

2.2 Classification of Age, Number and Duration of Rounds (Amateur vs. Professional)

Like many other sports, boxing offers a system that permits athletes to compete at their own level and to progress according to their potential and objectives. Although there are many possible ways to progress, generally boxers will start by competing in the amateur ranks to learn the sport and acquire some experience. There are usually 2 general classes recognized in amateur boxing: the beginner class (under 10 fights) and the open class (10 fights and over). Beginner class boxers usually don't fight open class boxers. According to the Amateur International Boxing Association (39), the category of boxers is determined by their year of birth. For school boys and girls of 14 years old and under, the difference of age between 2 boxers should not be more then 2 years and all competitions should be managed by national and continental organizations. After that, boys and girls from 15 to 16 are categorized as junior boxers and from 17 to 18 as youth boxers. For men and women boxers, the age category is from 19 to 34 and they are categorized as elite boxers even though there could be a wide range of calibers within such an "elite" category. Although boxers are always imposed a 1-minute rest period between rounds, the duration and the number of rounds varies between categories. For junior boys and girls, fights are 3 rounds of 2 minutes, for youth girls and women elite they are 4 rounds of 2 minutes and for youth boys and men elite they are 3 rounds of 3 minutes. Once a boxer is 18 years and older (91), he or she is allowed to compete as a professional where the bouts are between 4 to 12 rounds of 3 minutes for men and 4 to 10 rounds of 2 minutes for women depending on their level of competition (40,42,89,91,92). Professional boxers are also always imposed a 1-minute rest period between rounds.

2.3 Weight Categories (Amateur vs. Professional)

At the beginning, weight categories didn't exist and boxers could fight some opponents with large weight differences, which generally made it less competitive and much more dangerous. For such reasons, the introduction of weight categories was necessary. Currently in amateur boxing (effective from September 1, 2010), 13 weight categories exist from 46 to 80+ kg for junior boys and girls, 11 categories from 45 to 81+ kg for youth girls and elite women and 46 to 91+ kg for youth boys and elite men (39). For professionals, 17 categories exist from 48 to 91+ kg for male (40,93) and up to 18 categories from 46 to 86+ kg for female boxers depending on the organization (41,42,87,90,92). But even nowadays, it is still frequent to see some weight differences between boxers in the same weight category during a fight. In combat sports, a special cultural tradition that boxers often favor is dehydrating to "make weight" and than rehydrating for the fight. Therefore, amateur boxers can weigh approximately 0 to 5+ kg heavier during the fight since they have to "make weight" the day of the fight and professionals can sometimes weigh up to 5 or 10+ kg heavier since the weigh-ins are the day before the fight. That factor is important to consider when discussing or choosing a weight category for a boxer. Fortunately, in scientific papers related to the aerobic fitness of boxers or the metabolic requirements of boxing exercises, reported weights are usually the average (Mean) and standard deviation (SD) of actual weight at time of the study. On the other hand, these weights do not necessarily correspond to the competition weight category of the boxers.

2.4 Training vs. Competition

A good boxing training needs to include technical, tactical, mental and physical skills. But in order to optimize the use of technical, tactical and mental skills, boxers need to be properly trained and physically fit enough so that they can utilize those qualities during a fight without being sidetracked by physical fatigue. Therefore, to be successful the fitness level of boxers must meet the physical and metabolic requirements of both, training and fighting. Because a boxing fight is generally very intense, exercises during training should also be very intense. But to be fit for fighting, boxers need to know what an actual fight requires and how they can prepare for it in the gym. Since it is hard to predict how a fight will unfold and what will be needed to win, boxers usually try to prepare themselves for every possible scenario with an emphasis on the most probable ones. Thus in training, boxing teams usually try to optimize the physical fitness of the boxers and to develop tactics based on their knowledge of what might be required during the fight. Once they are comfortable with their plan, the boxers usually try to practice it in sparring to specialize their preparation and to learn how to cope with the challenges. Consequently, that's why sparring should be executed as close to fighting as possible in virtually every aspect and on every level. The same approach applies for other specific forms of boxing training like pad work, punching bag… In boxing, a common expression says that the more you sweat in the gym, the less you bleed in a fight. Although that expression is not to be taken literally, it gives a general idea of the state of mind under which some boxers prepare for a fight.

2.5 Types of Stances and Punches

Two different types of stances exist in boxing and they are called "orthodox" and "southpaw". Orthodox fighters are usually right-handed and are much more common. During a fight, they stand sideways with their left foot in front while keeping their right foot in the back. Southpaw fighters are much more uncommon and are usually left-handed fighters who stand the exact opposite way. Since there are fewer southpaws and since fighting against one is tactically and technically much different than fighting an orthodox fighter, southpaw fighters often have more success in boxing (32). Occasionally some boxers will transition from one stance to the other during training or fighting, but it is quite uncommon. When punching, a boxer should always hit the opponent with his knuckles while making a fist with his hand. In amateur boxing, that part of the glove is usually covered with a white spot. Three different types of punches for both hands are accepted and they are straights, hooks and uppercuts and must be done while the boxer is standing on his feet. One of the most common punches to be used is called the jab, which is a straight left hand for an orthodox fighter and a straight right hand for a southpaw. On the flipside, the straight right hand for an orthodox fighter or the straight left hand for a southpaw is usually a power shot. It should be understood that the type, power and relative frequency of punches (overall style of the boxer) will directly affect the metabolic requirements of boxing (61).

2.6 Competition Uniform and Equipment (Amateur vs. Professional)

In amateur boxing, the color of the gloves and headguards are imposed and one boxer has to wear red while the other wears blue as their respective corners. To compete, they must wear the following equipment: a protective headguard, a gumshield (mouth guard), bandages (hand wraps), 0.28 kg (10 oz) gloves, a cup protector, a vest (singlet), a pair of trunks (shorts) and sox with a pair of light boots or shoes that should not be higher than the knees. In addition, females must wear a breast protector (39). For professionals, the equipment is similar, except they cannot wear a headguard during competitions, the color of the uniform or equipment is not imposed, male boxers cannot wear a vest and the size of their gloves varies between 0.23 kg (8 oz) for males up to 67 kg and females up to 64 kg and 0.28 kg (10 oz) for heavier males and females (42,89,93). Amateurs and professionals usually practice sparring with ~0.45 kg (~16 oz) gloves for safety reasons and fight with smaller gloves. The fact that they practice with heavier gloves might affect the metabolic requirements of boxing exercises, but so far no study has demonstrated its effect.

2.7 Conclusion

All these differences in the rules and regulations and their changes through time have had a significant impact on boxing and the way boxers practice the sport. Obviously it also affected the aerobic fitness of boxers and the metabolic requirements of boxing exercises and it will be reflected by the variability of the results reported by literature in the following sections.

3.0 AEROBIC FITNESS OF BOXERS

Before discussing the aerobic fitness of boxers, it is necessary to understand the issues behind the concept of maximal oxygen uptake (VO_2max) (Section 3.1). Then, after giving the general VO_2max results (Section 3.2), it will be important to distinguish ergometer effects (Section 3.3), gender effects (Section 3.4), age and body weight effects (Section 3.5), competitive level effects (Section 3.6) and to compare boxing with other sports (Section 3.7). All of those sub-sections put together will help to better understand the aerobic fitness of boxers and its importance.

3.1 Concept of Maximal Oxygen Uptake (VO_2max)

VO_2max is defined as the plateau of steady state oxygen consumption (VO_2) as a function of increasing exercise intensity. VO_2max is specific to the type of exercise used to measure it and the most common ways are treadmill and leg ergocycle. Values reported in this review are mostly limited to these two modes of exercise. Although many criteria are defined to acknowledge the plateau phenomenon (63), the majority of references quoted in this review do not mention them. The expression VO_2peak is usually used when the plateau phenomenon is not observed. In well-motivated subjects such as athletes, including boxers, there are usually no differences between VO_2max and VO_2peak values obtained during continuous (no plateaus) and discontinuous (plateau) incremental protocols or during a subsequent confirmation phase (23,63,70). Thus, VO_2max values reported in this review either represents VO_2max or VO_2peak values.

Only relative to body weight VO_2max values ($ml \cdot kg^{-1} \cdot min^{-1}$) are retained in this section. Reported absolute ($L \cdot min^{-1}$) values were converted in relative values when body weight of the subjects was available. Since the ability to move in the ring and to throw punches is muscle mass dependent, the $ml \cdot kg^{-1} \cdot min^{-1}$ unit appears more pertinent.

3.2 Maximal Oxygen Uptake (VO_2max) of Boxers

An attempt was made to gather all available information on the VO_2max of boxers and to translate it into an exhaustive table (Table 1). General and specific observations are made from table 1. Boxer's values are then compared to values obtained for other sports.

Table 1 reports VO_2max values from the literature according to sex, number of subjects, age, weight, height, level of boxers and the ergometer on which VO_2max was measured. However, as we can see (Table 1), not all studies report the type of ergometer used, the sex, age, weight and levels of their boxers. Since our objective here was to report as much VO_2max data possible and because VO_2max depends on each one of these factors, table 1 reports overall values from 32.5 to 65.3 $ml \cdot kg^{-1} \cdot min^{-1}$ with an average of 56.1 $ml \cdot kg^{-1} \cdot min^{-1}$ with a standard deviation of ±6.4 between studies or an average standard deviation of ±4.4 within studies. Subsequently an effort was made to isolate every one of these factors and to discuss their effect on the VO_2max.

Ref.[1]	Level as reported	Sex	Subj.[3]	Age (yr)		Weight (kg)		Height (cm)		VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)		
#	Boxers	M / F[2]	n	Mean	SD	Mean	SD	Mean	SD	Exercise	Mean	SD
6	International	M	-	-	-	-	-	-	-	-	65.0	-
10	Elite	M	5	21.8	1.7	61.6	13.5	167.0	8.1	Ergocycle	60.6	3.9
10	Elite	M	5	27.2	1.5	77.8	15.7	176.4	7.8	Ergocycle	55.9	4.6
11	-	-	15	11.0	-	33.5	-	-	-	Ergocycle	65.3	8.7
11	-	-	17	12.0	-	39.9	-	-	-	Ergocycle	60.4	6.4
11	-	-	14	13.0	-	44.5	-	-	-	Ergocycle	60.3	6.8
19	National & International	F	20	19.7	2.2	57.6	7.7	159.9	4.8	Treadmill	52.1	6.9
22	Olympian	M	9	-	-	-	-	-	-	Step test[4]	49.9	2.6
22	Olympian	M	12	-	-	-	-	-	-	Step test[4]	49.0	2.0
27	National team	-	7	23.8	2.6	77.1	11.9	178.7	6.2	Treadmill	62.1	3.6
27	National team	-	13	25.0	3.2	79.0	18.3	179.5	7.9	Treadmill	60.5	7.5
27	National team	-	9	24.2	2.9	72.6	17.1	178.1	11.9	Treadmill	61.0	4.9
28	National	M	8	23.8	4.8	61.4	13.3	171.0	10.8	Treadmill	49.3	6.1
30	National team	M	7	21.0	1.6	52.3	3.6	160.0	3.9	Treadmill	57.9	2.4
30	National team	M	10	23.6	1.8	62.7	2.3	171.9	4.9	Treadmill	56.5	1.9
30	National team	M	9	24.2	1.7	80.0	8.7	177.6	3.6	Treadmill	49.6	3.7
31	Elite	-	8	22.3	1.5	77.4	1.4	177.1	2.3	Treadmill	57.5	4.7
35	-	-	-	-	-	100.0[5]	-	-	-	-	32.5	-
48	National team	M	13	-	-	-	-	-	-	Treadmill	64.7	6.3
49	High level	M	7	21.7	2.0	64.7	14.3	173.9	6.6	Treadmill	64.6	6.5
49	High level	M	6	19.0	-	63.0	11.7	175.3	6.9	Treadmill	62.7	4.6
49	High level	M	5	17.0	-	54.4	11.1	164.4	5.8	Treadmill	54.9	4.3
52	National	M	30	17.6	2.9	53.6	4.1	174.0	6.0	Treadmill	54.6	4.7
52	National	M	30	22.1	3.1	76.7	10.9	179.0	8.0	Treadmill	61.7	9.0
52	National	M	7	17.4	2.6	53.1	3.5	176.0	5.0	Treadmill	58.3	2.2
52	National	M	7	17.5	1.5	63.4	3.2	174.0	6.0	Treadmill	56.8	2.1
52	National	M	7	18.1	1.5	74.6	5.4	178.0	5.0	Treadmill	51.5	2.1
53	Beginner	M	10	15.0	-	-	-	-	-	Ergocycle	52.4	-
53	Beginner	M	10	15.0	-	-	-	-	-	Ergocycle	51.7	-
58	Professional & Amateur	M	6	15.0	-	50.0	-	-	-	Treadmill	58.5	2.6
58	Professional & Amateur	M	8	22.0	-	57.0	-	-	-	Treadmill	62.0	1.8
58	Professional & Amateur	M	24	22.0	-	68.0	-	-	-	Treadmill	58.8	5.8
58	Professional & Amateur	M	4	22.0	-	81.0	-	-	-	Treadmill	54.9	4.2
59	National	M	-	-	-	-	-	-	-	-	58.3	-
61	National team	M	7	22.4	1.8	64.6	13.5	174.3	7.6	Treadmill	54.2	4.5
62	Major league	M	5	-	-	56.2	-	167.0	-	Ergocycle	50.1	-
62	Major league	M	5	-	-	85.2	-	185.0	-	Ergocycle	47.8	-
62	Major league	M	5	-	-	68.2	-	174.0	-	Ergocycle	47.8	-
65	College	M	6	19.7	0.8	57.9	4.2	165.8	5.2	Ergocycle	51.1	3.1
78	International	M	23	26.0	-	62.5	10.8	-	-	Treadmill	63.8	4.8
78	International	M	26	17.0	-	65.3	13.0	-	-	Treadmill	49.8	3.3
82	National team	M	33	20.6	3.4	67.8	11.0	171.1	7.3	Treadmill	55.8	4.9
84	National & International	M	16	20.7	1.9	68.4	10.0	176.0	9.0	Treadmill	62.2	3.1
94	National	M	5	17.8	0.4	61.9	3.8	177.6	2.2	Shuttle	54.6	3.6
Mean			12	19.9	2.2	64.7	9.4	173.4	6.4		56.1	4.4
SD			8	4.0	1.0	13.1	5.0	6.0	2.4		6.4	1.9
n			41	35.0	22.0	37.0	26.0	27.0	24.0		44.0	36.0
Min			4	11.0	0.4	33.5	1.4	159.9	2.2		32.5	1.8
Max			33	27.2	4.8	100.0	18.3	185.0	11.9		65.3	9.0

Table 1. Illustration of VO_2max values reported in the literature for different groups of boxers. [1]*References,* [2]*Males/Females,* [3]*Subjects,* [4]*Sub-max step test,* [5]*Heavyweight estimate.*

3.3 Ergometers (Treadmill vs. Ergocycle)

Two classic ergometers used to measure the VO_2max are the treadmill and the leg ergocycle. Because more muscle mass is involved during running than pedaling, when tested on the two ergometers in the same experimental conditions, most subjects will display 5-15% higher values on the treadmill (7,16,34). In highly trained cyclists however, VO_2max values are similar or possibly even higher on the leg ergocycle (5b).

From the results reported in table 1, the overall average VO_2max of boxers was 57.6 $ml \cdot kg^{-1} \cdot min^{-1}$ for running and 54.9 $ml \cdot kg^{-1} \cdot min^{-1}$ for pedaling. These results correspond to a 4.7% difference, which is practically equivalent to the 5-15% previously mentioned (7,16,34). However, it is important to note that these average results were obtained with subjects of different sex, age, weight, and level. Since each one of these factors can influence the VO_2max we cannot generalize that 4.7% is the average VO_2max difference between treadmill and ergocycle for boxers. In some studies (Table 1), the ergometer type was not indicated and it was obviously difficult to compare these values to other reported values, consequently they were disregarded from these comparisons. Even though no study reports VO_2max values obtained with the same boxers on the two ergometers, we would normally expect the usual 5-15% difference since boxers are not trained cyclists.

3.4 Differences Between the Sexes (Males vs. Females)

Generally when comparing untrained males and females who participate in the same activities with similar volumes and intensities, men have a higher VO_2max than women due to a higher cardiac output, stroke volume and different blood & body composition (68). Typically, that difference is estimated to be more than 40% when expressed in absolute VO_2max ($L \cdot min^{-1}$), approximately 20% for relative VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$) and less than 10% when expressed in kilogram of lean body weight (14a). One study compared the effect of sex on the VO_2max between untrained and trained individuals of 18-31 years old and found a similar difference of 24% for untrained and 22% for trained subjects when expressed in $ml \cdot kg^{-1} \cdot min^{-1}$ (68). However, when comparing the sex effect for trained subjects, it is necessary to consider their respective sports. Depending on the requirements of the sport, sometimes the VO_2max difference can be much smaller. For example, in basketball and soccer almost no difference was reported between males and females with a range from 43-60 and 54-64 ml·kg^{-1}·min^{-1} for males and 40-60 and 50-60 ml·kg^{-1}·min^{-1}for females, respectively (86).

In table 1, only one study (19) reported a VO_2max value for females and they found 52.1±6.9 ml·kg^{-1}·min^{-1} for a group of 20 national and international boxers from India (19.7±2.2 yr, 159.9±4.8 cm, 57.6±7.7 kg) that were tested on the treadmill. Although it is difficult to generalize that to all female boxers of that level, that value is slightly lower than the average treadmill value of 57.4 ml kg^{-1} min^{-1} for males of all physical characteristics, age and level (22 groups, Table 1). When the sex of the boxers was not mentioned, it could be assumed that they were also male boxers since boxing is often perceived as a male sport (26 groups, Table 1). Then, that would correspond to a 9.2 and 10.1 % difference with females for male and assumed to be male boxers, respectively. Lastly, data from another group of national and international male boxers (Table 1, (84)) tested on the treadmill was of 62.2±3.1 ml·kg^{-1}·min^{-1}, which this time makes a larger difference of 16.2 %, and that would be more consistent with the general sex effect in the literature.

Although interesting, it cannot be concluded that these results offer a proper overall comparison of the sexes primarily due to the lack of data reported for females. As for the 2 same level articles (19,84), they offer a seemingly better comparison of the sexes for boxers of those "levels", but since other male boxers of practically the same level have various VO_2max (Table 1), these results cannot be generalized as representative overall values for the sexes or level of boxers. Moreover, because of the impossibility to provide a large-scale study with many subjects of both sexes who undergo the same study protocol that also considers the various influencing factors of VO_2max, a proper sex effect on the VO_2max for boxing cannot be concluded thus far and further research is necessary. However, It could be assumed that sex differences in VO_2max are similar in boxing than in other free-standing sports.

3.5 Age and Body Weight Effect

VO_2max decreases with age and its rate of decline is extremely variable between individuals. Its been reported that its rate of decrease was of approximately 30% between 20 and 65 years old with a greater fall after the age of 40 (14b). For general population groups, one study reported a decrease from 47-56 to 28-35 ml·kg^{-1}·min^{-1} for males of 10-19 and 70-79 years old, respectively, and a decrease from 38-46 to 20-27 $ml \cdot kg^{-1} \cdot min^{-1}$ for females of 10-19 and 70-79 years old, respectively, which represents approximately a 10% decrease per decade (86). In addition, two other studies reported an average decrease of 0.46 and 0.54 $ml \cdot kg^{-1} \cdot min^{-1}$ per year for males and females, respectively (44,45). Although, a decrease in relative VO_2max is noticed with an increase of age in every case, sometimes it is only due to the increase in body weight. When expressed in absolute values ($L \cdot min^{-1}$) the VO_2max can remain the same, but when expressed relatively to body weight ($ml \cdot kg^{-1} \cdot min^{-1}$), it will show a decrease. In other situations, it can be due to the decrease of maximal heart rate or the cardiac output and consequently the oxygen-transporting potential becomes affected (5a). Furthermore, even if masters athletes have higher relative VO_2max values, they also are affected with a decrease in VO_2max even when keeping their weight constant, simply due to the aging process. For example, former champion runners of 47-68 years old evaluated 25-43 years after their competitive careers in track, showed a decrease from 71.4 to 41.8 $ml \cdot kg^{-1} \cdot min^{-1}$ (41.5%) compared to a decrease from 50.6 to 36.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (27.9%) for non-athletes of equivalent age (71). As we can see, even though former champion runners maintained a higher VO_2max at all time, they had a higher decrease in %VO_2max with age than non-athletes. However, for highly trained master runners who continued training intensively from 25.7±1.1 to 47.2±1.2 years old, the decline was from 68.8±1.7 to 59.2±1.3 $ml \cdot kg^{-1} \cdot min^{-1}$ which represents an average decrease of 14%. As for older master runners who continued training to stay in shape from 46.8±3.1 68.4±2.7 years old, the decrease was from 60.3±4.2 to 40.7±2.3 $ml \cdot kg^{-1} \cdot min^{-1}$, which represents an average decrease of 32.5% (83). As observed, the decrease with age is inevitable, but the longer intense training is sustained, the smaller will be the decline in VO_2max through time.

Concerning the general age effect observed in the general population or in other sports, it is difficult to confirm if it applies to boxers in this review since the average age of the 44 inventoried groups (Table 1) of boxers (19.9 yr) was quite homogenous with a standard deviation of only 2.2 years. Surprisingly though, one of those studies reported a significant difference of 63.8±4.8 and 49.8±3.3 $ml \cdot kg^{-1} \cdot min^{-1}$ for senior and junior international boxers of 26 (18-34 yr) and 17 (16-17 yr) years old, respectively, of similar body weight. The authors said that such a difference might be attributed to the age, level of maturation or the length of time engaged in aerobic training (78). However, at such an age, the general age decrease effect is generally mostly due to increased body weight and since the body weight of these boxers was the same it is difficult to attribute that difference to age or maturation. The training load is however a possible explanation as well as a better genetic or talent background for the boxers that are still active and successful in older age categories.

The body weight effect on athletes is especially important when the weight has to be carried. In the same disciplines or at the same level of aerobic training or fitness, heavier athletes usually have higher absolute VO_2max but this advantage disappears when they have to carry a heavier body weight. In fact, when we calculate relative to body weight VO_2max to correct or to compensate for body weight, we mathematically assume that absolute VO_2max is proportional to weight exponent 1 (kg^{-1}) while allometric studies have shown that absolute VO_2 as a function of weight is proportional to weight exponent between 0.70 to 0.75 (kg^{-1}) (13). Thus using a unit such as $ml \cdot kg^{-1} \cdot min^{-1}$ yields lower VO_2max values or lower submaximal VO_2 requirements in heavier individuals. Furthermore, heavier athletes tend to be less active or prone to aerobic training, particularly in boxing, which also can yield lower VO_2max values. For example, one study (75) compared the absolute and relative VO_2max values of various 20+ year old boxers from the French national boxing teams between the years of 1989 and 2000 for the weight categories of super heavyweight, heavyweight, light heavyweight, middleweight, welterweight, super lightweight, lightweight, featherweight, bantamweight, flyweight and under 48 kg, and it can be seen that absolute values are higher in heavier boxers while the opposite was seen for relative to body weight values (Figure 1). The relative VO_2max values in figure 1 have been divided by 10 to facilitate visual comparison.

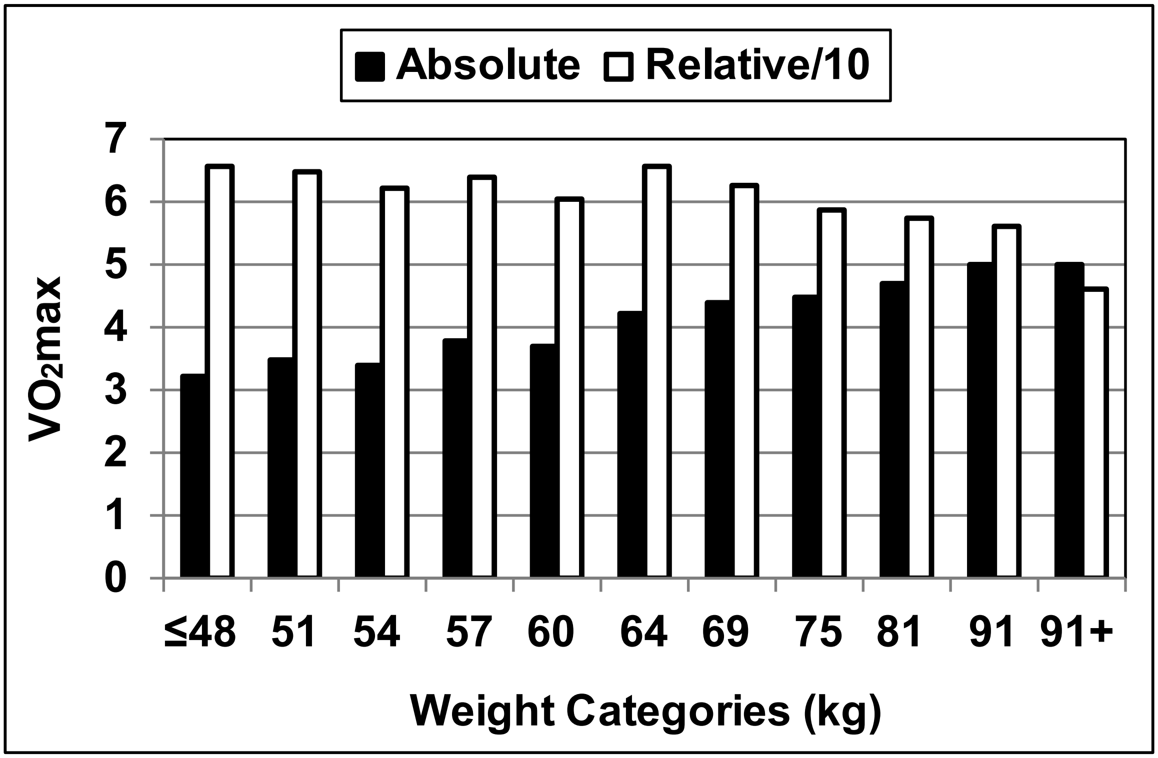

Figure 1. Relation between relative/10 ($ml \cdot kg^{-1} \cdot min^{-1}/10$) and absolute ($L \cdot min^{-1}$) maximal oxygen uptake (VO_2max) in different weight categories (75).

The weight effect observed in figure 1 is confirmed in the scatterplot (Figure 2) of relative VO_2max as a function of body weight from the data listed in Table 1. Results in figures 1 & 2 were obtained with average values of different groups or different studies.

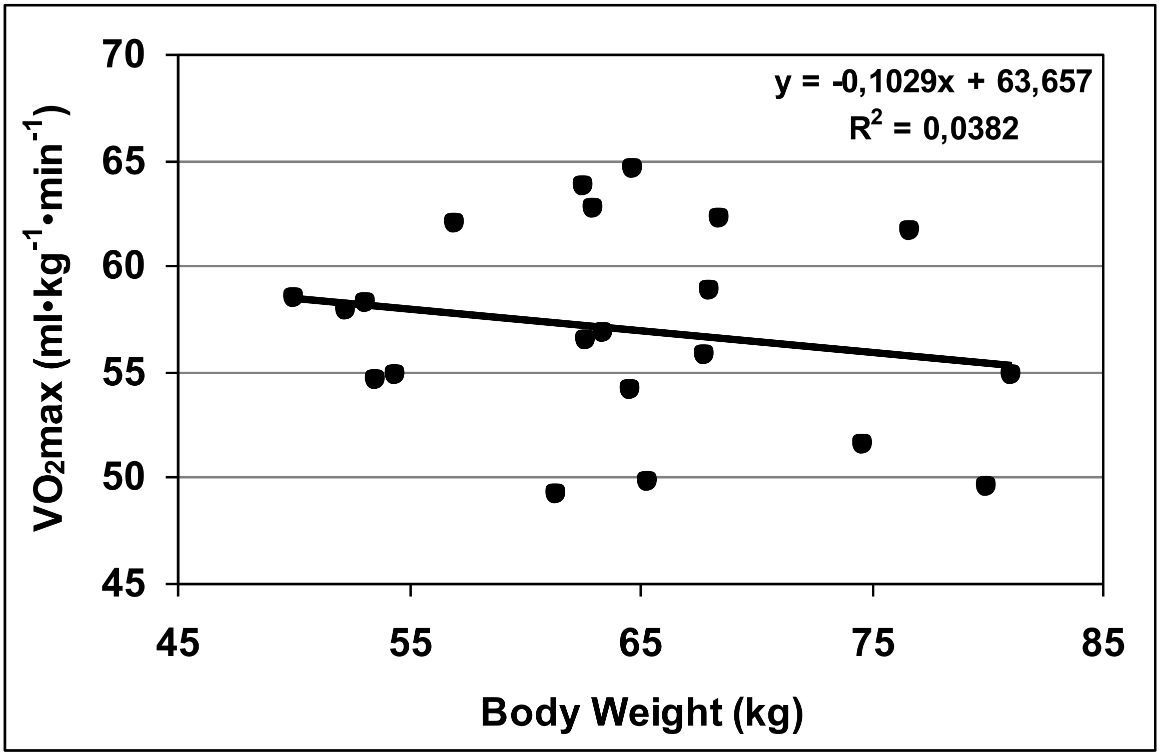

Figure 2. Relation between the body weight (kg) and relative VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$) measured on a treadmill for male boxers.

In summary, a general age effect on the VO_2max of boxers cannot be ascertained from table 1 due to the wide variability found in the results. But consequently, it could be supposed that generally boxers are not subject to experience any significant age effect since they are usually in similar age categories and all of them have some training experience that helps to slow down the decrease in VO_2max with age. Table 1 supports that hypothesis by showing a wide variability in the VO_2max results for boxers of similar age. However, that cannot be confirmed because of all the inconsistencies in the subjects overall characteristics (Table 1). As for the general VO_2max decrease observed with aging in adulthood, it could not be excluded, but data on older or master boxers is necessary to demonstrate or quantify it. On the other hand, during growth, some results indicate that VO_2max can increase significantly with age (78). Finally concerning the body weight effect on relative VO_2max, heavier boxers tend to be less fit. Thus it is important to consider the body weight when discussing VO_2max results obtained for different boxers.

3.6 Level of Boxers

"Training increases the maximal oxygen uptake as well as the percentage of it that can be taxed during a workout. Consequently, the intensity of the load required to produce an effect increases as the performance is improved in the course of training. The training load is therefore relative to the level of fitness of the individual. The fitter a person is, the more it will take to improve that fitness" (5c). However, the VO_2max cannot be considered as a precise predictor of performance in elite athletes. For example in a sport well known for high VO_2max values, the winner of a marathon is not necessarily the athlete with the highest VO_2max (20). It is possible that two marathoners may have the same VO_2max, but for different running speeds. Furthermore, the one with the lower running speed might be able to endure a higher %VO_2max and that may reward him with a better result. This is even truer with boxers whose performances also depend on other skills besides bio-energetic capacities. Therefore a high VO_2max value can be a helping factor to performance but it is not the sole predictor.

All the missing information, variability in the results and the discrepancies found between studies (Table 1) complicated the task of defining a level effect for boxing. Since it was not always clear what meant the levels associated to the groups, it could be hypothesized that the "beginner" level may represent a trained or untrained athlete with little to no experience in boxing. In that case, "beginner" boxers could mean a number of different things and it may only represent less experienced in boxing, but not necessarily less trained. That might explain why some beginner boxers have similar VO_2max values than some "superior-level" boxers. As for "superior-level" boxers, levels reported were often published under different names for seemingly similar level of boxers and also in some cases the level was not mentioned and it made it difficult to do direct comparisons. Therefore it was hardly possible to isolate the level effect and to discuss it specifically. On the other hand, because some similar levels seem to have various VO_2max values (Table 1), it could be hypothesized that perhaps a minimal level of VO_2max is required for boxing at a certain level and that afterwards other important factors might differentiate the level of success of boxers.

That being said, we believe that boxing only partially relies on aerobic fitness to sustain the high intensity of fighting without undue fatigue till the end of the last round.

Unless a boxer has a very low aerobic fitness compared to his opponent, the issue of the fight is possibly more dependent on technical, tactical, mental and overall physical skills of the boxer and his willingness to struggle and push through adversity. We think that the vast majority of boxers at amateur levels who only fight a few rounds on which most studies are done, manage to get the minimum aerobic fitness required for boxing whatever their level is. That is reflected by the fact that reported treadmill VO_2max values of male boxers are almost all within the 50 to 60 $ml \cdot kg^{-1} \cdot min^{-1}$ range. Those values are thus typical for amateur boxers. It is not excluded that professional boxers with longer fights might need higher VO_2max values to achieve success particularly in lighter weight categories where the sustained cadency of punching and overall motions are very high.

3.7 Boxing vs. Other Sports

Boxing is a particular sport with repetitive stop & go movements of fluctuating intensities and fairly short activity durations that requires a specific physical fitness. When discussing the aerobic fitness of boxing, it is interesting to see how it compares with different combat sports and other popular intermittent and continuous sports. Since studies often measure VO_2max while running on a treadmill and because it better reflects a general utilization of muscle mass like the following sports, only treadmill VO_2max values will be discussed in this section. Furthermore, due to the lack of female data in our compilation of VO_2max for boxing (Table 1), only male treadmill values will be used to compare boxing with other sports.

In this review, an average value of 57.4 $ml \cdot kg^{-1} \cdot min^{-1}$ was obtained for male boxers. For other combat sports, VO_2max values of 59.9, 57.5, 59.2, 54.9 and 55.7 $ml \cdot kg^{-1} \cdot min^{-1}$ were reported for male Fencing, karate, judo, kendo and wrestling athletes (33,37,46,77,80), respectively. In other intermittent sports, values of 58.2, 53.4, 57.5, 56.8, 59.1 $ml \cdot kg^{-1} \cdot min^{-1}$ were reported for male tennis, ice hockey, basketball, handball and football (2,25,26,47), respectively, and in continuous sports, values of 52.9, 61.4, and 81.3 7 $ml \cdot kg^{-1} \cdot min^{-1}$ were reported for 100-200m, 400m and 10 000m-marathon male runners (48), respectively.

When comparing the average VO_2max value obtained for boxers to the values reported for combat sports or other intermittent sports above mentioned, boxing appears to be quite similar to most of them, which might be due to the similarities in the nature of the sports with frequent stop & go movements and variations of intensities. However, when comparing to a continuous sport like running, only the values obtained for the shorter distances of 100-400m were similar. Such results could partially be because the shorter distances are explosive disciplines of intense short durations kind of like boxing, while longer distance runners are trained with the objective of enduring a relatively high aerobic intensity for a much longer period of time. Thus, from these results we can observe that VO_2max seems to be sport specific and that it has a tendency to be closer between the sports of similar nature. However, despite these interesting comparisons, it is important to consider that these results were obtained with athletes of various levels with different methodologies. Therefore, they represent an approximation of the aerobic fitness required for the selected sports and give a general idea of the category in which they stand.

3.8 Conclusion

In summary, as discussed in this section many factors can affect the VO_2max. Ideally, previous studies on boxing would have isolated these factors and provided more specific methodologies. Unfortunately, it was not always the case and for that reason an effort was made to regroup as many articles possible, including all of those factors, into an exhaustive table (Table 1) and to detail their effect afterwards. Although interesting, it is necessary to be careful when generalizing from such compilations. Sometimes it is hard to clarify certain issues or to provide a proper interpretation or comparison due to the lack of studies available or the significant amount of missing information in these articles. Therefore, future studies should be more meticulous when developing and reporting their methodologies and results.

4.0 METABOLIC REQUIREMENTS OF BOXING EXERCISES

The three boxing exercises being discussed in this section are all classic training exercises of the sport. Briefly they consist of: 1) sparring, a simulation of boxing with a partner in the gym, 2) pad work or punching on a partner's pads or mitts and 3) punching bag or punching on a heavy bag. Each on of these exercises are very common to boxers and are practiced in boxing gyms around the world. However, depending on the rules and regulations, the way of practicing these exercises, the physical characteristics, the sex, and the level of boxers, the metabolic requirements of these boxing exercises can vary considerably as we shall see.

Since it is difficult to interpret reported values of the metabolic requirements without understanding the principles and limits of the methods, techniques and metabolic indicators used in boxing studies, this section will first discuss these aspect successively focusing on VO_2, heart rate, (HR), blood lactate concentration [LA] and rated perceived exertion (RPE) (Section 4.1). Thereafter, the metabolic requirements of sparring (Section 4.2), pad work (Section 4.3) and punching bag (Section 4.4), will be described and discussed taking into consideration methodological limitations and conditions in an attempt to clarify some of the variability or discrepancies found in the reported values.

4.1 Principles and Limitations of Metabolic Measures (VO_2, HR, [LA] and RPE)

The measurement of the metabolic requirements of an activity could be obtained with different approaches that do not always yield the same results, which explains some of the discrepancies in values reported in the literature. Some approaches are better than others and give a higher level of validity to the reported values. However, some general principles must be observed.

If the activity being studied includes many different types of exercises or motions expected to have different metabolic requirement and lasting different percentage of total activity, it is preferable to split the activity and measure separately each of its components.

Similarly, if the studied activity could be done at different intensities or tempos, it is important to control the tempo either by imposing it or at least measuring it in order to associate the obtained energy cost values to the appropriate tempo. For running, that means measuring the metabolic cost at various speeds. For sparring, pad work and punching a bag, the punching frequency may be imposed or recorded and subjects being instructed to do the activity at a relatively constant intensity. But again without knowing the punching power, the metabolic cost may vary substantially between individuals and studies. In order to obtain a valid measure of the metabolic requirement of an activity, that activity must be standardized, not only for tempo but also for glove's weights, for example…

Furthermore, the activity must be performed long enough to obtain some kind of metabolic steady state. If the activity is too intense to be maintained long enough to reach a steady state, a gross estimation could be obtained by extrapolating the metabolic cost measured at lower intensities assuming that the cost efficiency is the same in anaerobic state.

Another rule is that the technique used to measure the VO_2 cost should not modify the activity itself. For example, measuring the metabolic cost of sparring or boxing with meteorological balloons, not only modifies the motions of the activity but also does not enable the boxers to hit each other on the face. Thus only modified sparring or boxing could be measured with meteorological balloons or a portable VO_2 device such as the $K4b^2$. That is why some studies use the HR/VO_2 regression to estimate the O_2 cost of field activities. But it must be understood that such calibrations must be individually established using the same type of activity. For example, the use of a treadmill or bicycle regression to estimate the cost of arm work or the cost of boxing is not valid (65). Furthermore, and since maximal HR is reached at around 85 %VO_2max in constant intensity load (21,60,72), HR/VO_2 regression curves are useless to estimate the cost of activities above such intensities… Finally, the accuracy of that technique is usually lower than the one obtained when measuring VO_2 itself (51,64,65,79). Most studies reporting metabolic requirements of boxing exercises are not respecting many of these rules 1) making it difficult to interpret the results 2) explaining large differences in reported energy costs and 3) making it difficult to obtain a consensus. Still HR, [LA] and RPE are easy to measure during boxing and boxing exercises and are often reported. They are gross indicators of boxing requirements and will be reported as such, the main focus of this review being VO_2 estimates of boxing exercises.

Two more points still need to be addressed in this section. Since boxing exercises often mimics boxing competitions, exercises are often made in sets of three or four rounds. Thus reported metabolic values could be for each round, the average of each round, the third or fourth round or the first round if only one round was done, or peak values instead of mean values. Since we were interested in the mean maximal load of boxing exercises on the metabolic system we reported third round values when that was obvious in a study. Otherwise, we had to assume it was the case although it was not always clearly indicated if it was peak or mean of all rounds or first or third or fourth round. Considering that increased fatigue from round to round may raise VO_2 values (19), that adds variability to reported results. But variability could also be due to subject's differences in age, gender, weight, experience level and to measuring methods…

As a final technical note in this section, the VO_2 requirements values reported in this section were expressed relatively to body weight in $ml \cdot kg^{-1} \cdot min^{-1}$. Since the VO_2 requirements of boxing found in literature are often published under different units ($ml \cdot kg^{-1} \cdot min^{-1}$, $L \cdot min^{-1}$, METs, $kcal \cdot min^{-1}$, $kcal \cdot m \cdot^{-2} min \cdot^{-1}$, $kJ \cdot h^{-1}$…), conversion to $ml \cdot kg^{-1} \cdot min^{-1}$ were done when body weight of the subjects was available. Ultimately, when VO_2max was known, %VO_2max values were also provided.

4.2 Metabolic Requirements of Sparring

4.2.1 Description of Sparring

Boxing is a combat sport that involves two boxers fighting each other in a roped square ring under a predetermined set of rules and regulations administered by a referee. More precisely, the objective is for the boxers to punch their opponent to the anterior portion of the upper body with padded gloves as many times and as efficiently as possible while trying to avoid getting hit efficiently in return. Most effective punches are the ones who incapacitate the opponent to continue fighting or scores points by landing either on the body or the head and less effective punches are the ones that can potentially become effective, but that don't actually score points in the moment like hitting the arms or even worse nothing at all. Effective or not, all the thrown punches affect the energy expenditure of boxing. Different exercises are used to prepare a boxer for a fight, but the most comparable and specific exercise is sparring because it is simply boxing in a non-competitive situation in the gym training ring. Thus, the way a boxer does sparring in the gym with a partner and the way he fights with an opponent in a competition can be quite similar in every aspect. However, depending on the style and the level of the opponent or the sparring partner, it can have an effect on the metabolic requirements of these activities. That's why it is important to choose proper sparring partners when preparing a boxer for a fight and to monitor the trainings if possible. Often times, boxing teams will choose boxers of similar level that can simulate certain specific boxing styles to achieve the desired training effect that will ultimately help fine-tune the boxer to perform better on fight night.

Although the sparring practice could be very hard against fierce and proud partners, the stakes and the competitive stress of a competitive boxing fight are not the same, as we all know. Some studies reported metabolic values for boxing but a closer look at their methodology, indicates that sparring (or "modified" sparring) is in fact the exercising mode. Even when it is not clear, true boxing values are very rare because the rules do not permit such measurements in competitive fights.

4.2.2 Limitations of the Metabolic Measures for Sparring

As said before (Section 4.1), collecting VO_2 during a fight is hardly possible since the measuring apparatus is not permitted into the ring during an official fight and regardless of that, wearing a facemask or some measuring apparatus do not allow punches to the face and hinders usual motions of boxers. Thus even for sparring, the only possible way to measure the VO_2 of "true" sparring would be to use less reliable indirect methods. So far, previous studies used modified sparring or indirect methods to measure the VO_2. On the other hand, measuring HR, [LA] and RPE during sparring and boxing are quite easy and they do not hinder regular motions of boxers, however, getting the permission to measure them during an actual boxing competition remains a difficult issue. Of course, regardless of the approach used to measure VO_2, the conditions (glove weight, aggressive or defensive strategies…) will also affect the cost of sparring.

4.2.3 Metabolic Requirements of Sparring

In Czech Republic (73,74), one study used meteorological balloons to measure the VO_2 of 15 male boxers (17.5±1.6 yr, 171.7±5.7 cm, 63.3±10.8 kg) of level 1 and 2 performance classes during a "match" lasting 3 min [*sic*]. VO_2 values that reached 30.8±4.4 $ml \cdot kg^{-1} \cdot min^{-1}$ for the first 2 min and 38.9±5.9 $ml \cdot kg^{-1} \cdot min^{-1}$ for the remaining min were obtained for what seemed to be in reality an attempt to simulate a match. During the testing sessions, only one boxer was evaluated at the time and that boxer was not allowed to be punched to the head to avoid disrupting the face mask and it was mentioned that while the investigated boxer tried to perform as close as possible to reality the opponent fought in a rather defensive way. In India (18,19), treadmill HR/VO_2 regression were used to estimate the VO_2 cost of women sparring (19.7±2.2 yr, 159.9±4.8 cm, 57.6±7.7 kg) and average values of 40.3±7.0, 45.0± 5.9 and 46.6±6.6 $ml \cdot kg^{-1} \cdot min^{-1}$ with peak values between 45.9±6.0, 48.4±6.1 and 50.5±7.9 $ml \cdot kg^{-1} \cdot min^{-1}$ for round 1, 2 and 3 (2-min rounds), respectively, were reported for national and international level boxers. Those values correspond to an average of 77.5, 86.5, 89.5 %VO_2max and a peak of 88.2, 93.0 and 97.0 %VO_2max for round 1, 2 and 3, respectively. In Belgium (69), a short review paper reported a range of 26.3-42.0 $ml \cdot kg^{-1} \cdot min^{-1}$ (7.5-12 METs) for the metabolic costs of "boxing" without adding any additional methodological information whatsoever. In America (3,4), both versions of a compendium on multiple sports and activities reported values of 31.5 and 42.0 $ml \cdot kg^{-1} \cdot min^{-1}$ (9 and 12 METs) for sparring and "in ring general", respectively [*sic*], without specifying methodological details however. In the UK (24), another compendium paper used the HR/VO_2 regression method to obtain a general estimation of the energy expenditure of various activities and found metabolic requirements for "boxing" of "equal or larger" than 23.1 $ml \cdot kg^{-1} \cdot min^{-1}$ (30 $kcal \cdot min^{-1}$) for 65 kg males and 21.8 $ml \cdot kg^{-1} \cdot min^{-1}$ (24 $kcal \cdot min^{-1}$) for 55 kg females. Also in the UK, a study on *"the food intake and the energy expenditure of cadets in training"* (85), displayed a table with VO_2 values of 43.1 and 27.0 $ml \cdot kg^{-1} \cdot min^{-1}$ (8 and 5 $kcal \cdot m \cdot ^{2} min \cdot ^{1}$) to illustrate the energy expenditure of boxing exercises such as "in ring" and "sparring", respectively, for a group of 77 cadets (19.8 yr, 178 cm, 1.83 m^2, 68 kg). But the origin of that table was not quite clear. In Japan (65), the HR/VO_2 regression technique was also used to estimate the VO_2 requirements but results depended on whether the standard curve was obtained on a treadmill, ergocycle or with basic boxing motions. For sparring, only results for one college level boxer (21 yr, 160.6 cm, 51.8 kg) were reported and average values of approximately 51, 49 and 56 $ml \cdot kg^{-1} \cdot min^{-1}$ were found which represent approximately 99, 95 and 108 %VO_2max, respectively, for a ~10 min sparring period that was part of approximately a 2 hour long continuous training session with unknown work-rest ratios. The sparring testing was done approximately after 35 min of warming up and shadow boxing. In this study, it is to be noted that VO_2max and HRmax were only measured on an ergocycle for all subjects. It is difficult to understand how ~108 %VO_2max could be maintained for ~10 minutes within a ~2 hour training session.

From the articles cited while describing the VO_2 of sparring and "boxing", HR values were sometimes reported with values that reached 161.8±11.6 $b \cdot min^{-1}$ for the first 2 min and 171.1±11.2 $b \cdot min^{-1}$ for the remaining min of the 3 min "matches" without specifying HRmax (73,74) and values for sparring of 171.0±11.0, 181.0±8.0 and 184.0±7.0

with peak values of 183.0±6.0, 189.0±6.0 and 193.0±7.0 $b \cdot min^{-1}$ for round 1, 2 and 3, respectively, which correspond to 86.4, 91.4, 92.9 and 92.4, 95.5, 97.5 %HRmax, respectively (18,19). One more study also reported HR, and they found average values of approximately 185 $b \cdot min^{-1}$ for one boxer sparring, which represents approximately 96 %HRmax (65). Other articles found in the literature offered a range of average HR values from ~170 to 200 $b \cdot min^{-1}$ for male sparring and boxing (9,15,30,50,52,65,76,78,84,94). Since VO_2 values were not reported in these studies, no parallel could be established between the responses of these two variables. Concerning [LA], only one of those studies reporting VO_2 also reported [LA] values and they found 10.1±2.1 $mmol \cdot L^{-1}$ collected between the 2nd and 3rd minute after round 3 (19). Other articles found in the literature offered a wide range from 7.1 to 17.1 $mmol \cdot L^{-1}$ for [LA] values collected at various times for males doing sparring and boxing (8,9,29,30,36,50,52,55,78,81,84). As for RPE, only one study was found and they reported values from 13±0.7 to 19±0.3 for male sparring without reporting sparring VO_2 values (76).

With all the variability or discrepancy found in the methodologies and the results, it is difficult to establish the metabolic requirements of classic formats of practicing sparring and boxing thus far. However, when considering those limitations some general observations can still be made. It seems that a minimum of about 25 $ml \cdot kg^{-1} \cdot min^{-1}$, an average of 40 $ml \cdot kg^{-1} \cdot min^{-1}$ and a peak of 50 $ml \cdot kg^{-1} \cdot min^{-1}$ or higher could be expected during these activities. Generally, the average VO_2 requirements during sparring or "boxing" seemed to be lower than the average VO_2max of the same boxers or the average of all boxers (56.1 $ml \cdot kg^{-1} \cdot min^{-1}$, Section 3, Table1), while reported VO_2peak values were closer (18,19). Exceptionally, one study (65) showed a very high average VO_2 value that was higher than the VO_2max value of their subject, however, that sparring %VO_2max value was also higher than their %HRmax which is quite unusual (108 %VO_2max vs. 96 %HRmax). Since the maximal test was done on an ergocycle, the authors said that it is possible that the boxer was more comfortable during sparring and therefore he could push harder during this exercise, in addition to mobilizing more muscle mass. Concerning the higher %VO_2max than %HRmax, we do not have any explanation for that, but we do believe it is suspicious. As for the round effect on the metabolic requirements, when such results were available some increase was noticed from round to round for VO_2 (18,19), just like it was the case for HR, [LA] and RPE in virtually every article (9,15,18,19,30,50,52,76,78,84). Since information such as punching frequencies was not reported, the exact cause of the increase cannot be confirmed. Of course, an increased fatigue state or a decreased efficiency from round to round could not be excluded. At the same time, it is also possible that boxers increase their intensity from round to round. We are quite hesitant to elaborate on specific sparring and boxing comparisons, since the exercises were not always well distinguished and sometimes it could lead to confusion. In some articles, the authors seemed to say that they evaluated boxing, but we have reasons to believe it was sparring. For example, one study said they evaluated "matches" which could be fairly interpreted as "actual boxing", but from the picture provided, the description (see above) and the fact that the matches only lasted 3 min in total, it was clearly not an official "boxing match" (73,74). Therefore it is believed that every VO_2 values reported were sparring values, while some of the articles cited for HR and [LA] (8,9,29,30,36,52,55,78,81,84,94) are actually reporting "boxing" values. From a theoretical point of view, only studies that used the HR/VO_2 regression could estimate "true" sparring VO_2 requirements. However, when the HR/VO_2 regression curve is determined with treadmill or ergocycle exercise (17,18,19,65) instead with actual boxing motions (65), the specificity of the results could be questioned. As indicted in section 4.1, the use of HR/VO_2 regression only yields gross VO_2 requirements for a group of subjects and unreliable estimates for an individual subject.

Concerning HR, [LA] and RPE, when measured alone (without any VO_2 measuring device), it is believed that they are representative of true sparring or boxing, since those measurements do not hinder or interfere with the usual motions of boxers or the punches to the face. Thus, the reported range for HR, [LA] and RPE values show the potential of fluctuation between rounds, boxers and testing protocols and confirms the importance of detailing the methodologies and monitoring such aspects like the punching frequency to better understand the results.

Finally, the only study (19) to report values of VO_2, HR and [LA] all together, found approximate average values of (44 $ml \cdot kg^{-1} \cdot min^{-1}$ or 84 %VO_2max & 177 $b \cdot min^{-1}$ or 90 %HRmax) and peak values of (48 $ml \cdot kg^{-1} \cdot min^{-1}$ or 93 %VO_2max & 188 $b \cdot min^{-1}$ or 95

%HRmax) for three 2-min rounds of true sparring and a value of 10.1±2.1 mmol·L^{-1} measured between 2-3 min after the 3rd round for a group of national and international women boxers. Those results give an idea of what might be required for such athletes during actual sparring.

4.2.4 Conclusion

Although VO_2 measurements are rare and not associated with "true" sparring and VO_2 estimates of "true" sparring from HR/VO_2 regression are less reliable, the bulk of our data indicates that a minimum of about 25 ml·kg^{-1}·min^{-1}, an average of 40 ml·kg^{-1}·min^{-1} and a peak of 50 ml·kg^{-1}·min^{-1} or higher is expected for sparing. Basic measures such as HR, [LA] and RPE are not very informative per se, but with the same subjects it enables comparison between rounds of true sparring or boxing and indicates an increase in the metabolic requirements from round to round. New methods need to be developed to measure VO_2 for true sparring.

4.3 Metabolic Requirements of Pad Work

4.3.1 Description of Pad Work

Pad work, is a very practical training exercise in boxing because it permits a very close interaction between a trainer and a boxer, during which many different aspects of boxing can be practiced. For example a training session can consist of working on offense, defense, handwork, footwork, speed, power, ring control, technique, tactic, intensity… Furthermore, any one of those aspects can be isolated and practiced on their own or they can all be mixed together and practiced as a whole. Thus, pad work can be much more complex than simply punching on some pads or mitts. The best place to practice pad work is in a boxing ring, because it allows the boxer to develop a sense of how to use the ring. But depending on the aspects being practiced it can just as well be practiced outside of the ring without much difference. To a certain extent, pad work is kind of a simulation of sparring and in fact, it is often during this exercise that technique is practiced and fine-tuned so that the boxer can eventually apply it efficiently in sparring or boxing. Consequently, that's why when training certain aspects of boxing during pad work, it is important to have a clear vision of the objective at last and to understand how to achieve it, so that the method being used is appropriate. In the same line of thought, when discussing pad work, it is important to understand the objective being pursued and the way of practicing the exercise to achieve it in order to better understand its purpose and if it reflects it well or not.

4.3.2 Limitations of the Metabolic Measures for Pad Work

Since pad work is only practiced as a training exercise, wearing different types of measuring apparatus does not interfere with any rules and regulations and it is perfectly acceptable and permitted to wear such equipment in the ring or elsewhere. The issue with measuring the VO_2 requirements of pad work appears during the actual measures. To a certain extent, wearing different types of apparatus might limit the usual motions of boxers and the normal functioning of this exercise, especially if the exercise is practiced with rugged vast movements, pad punches to the head and body of the boxer by the trainer, rope fighting simulations, footwork... In those situations, using HR/VO_2 regression curves seems to be the preferable technique, but once again its accuracy could still be questioned. On the other hand, if pad work is practiced in a more settled way, it could be fairly easy to measure its VO_2 requirements with a collecting gas valve in the face without much motion hindrance. Therefore, the efficiency of the measuring technique can vary considerably depending on the aspects being practiced during this exercise. Thus, it will be interesting to see what studies report on this subject. As for measuring HR, [LA] and RPE, they do not pose a problem at any moment during this exercise.

4.3.3 Metabolic Requirements of Pad Work

For pad work, since only 2 articles were found in the literature and because they only reported VO_2 and HR, both of these metabolic requirements will be reported together. In a Japanese study where sparring cost was measured and reported above (65), the VO_2 requirements of pad work was also measured with a group of 6 college boxers (19.7±0.8 yr, 165.8±5.2 cm, 57.9±4.2 kg), measuring VO_2 with Douglas bags or estimating it from HR/VO_2 regressions. Furthermore the specific protocol in which pad work was studied is unknown and so is the exact duration of the exercise. When the Douglas bag technique was used, it appears that pad work was done as a part of a continuous ~1 hour workout done after ~20 min of warm-up and shadow boxing; the pad work itself lasted ~5 to 10 min. For the HR/VO_2 regressions, it appears that pad work was done twice as a part of a continuous ~2 hour long training session, done in the following sequence of exercises: warming up, shadow boxing, sparring and pad work (trial 1 at ~45 min), followed by punching bag, punching ball and pad work (trial 2 at ~65 min); the pad work exercise lasted approximately 5 min for both trials. With both techniques the work-rest ratios were unknown. When measured with Douglas bags, peak values of 48.2±3.8 $ml \cdot kg^{-1} \cdot min^{-1}$ and 167.0±7.0 $b \cdot min^{-1}$ were reported which surprisingly represents, 94.3 $\%VO_2max$ and 87.0 %HRmax, respectively. On the other hand, when VO_2 was estimated from HR/VO_2 regressions, although it is unknown if the results represent peak or average values, results reported were of 44.4±3.6, 41.1±3.1 and 42.7±3.3 $ml \cdot kg^{-1} \cdot min^{-1}$ whether the HR/VO_2 regression was established on a treadmill, ergocycle or with basic boxing motions, respectively. Those values correspond to 86.9, 80.4 and 83.6 $\%VO_2max$ and in this condition HR values were not reported. To perform pad work at the same rate while wearing the VO_2 apparatus may be more difficult which would explain the higher VO_2 values with this technique as compared with the HR/VO_2 regression one. Furthermore, since it is unknown whether the HR/VO_2 results represent average or peak values, a possibility exists that they are indeed average values and thus that would explain why they are lower than the peak Douglas bag values. Furthermore, since the HR/VO_2 training session lasted almost twice as long, a possibility also exists that it affected the metabolic requirements.

The other study (12) to measure the requirements of pad work was conducted in South Africa and they measured the energy expenditure of a 1-hour noncontact boxing training session in which they practiced pad work from the 5th to the 23rd min. No specific details were given on the way of practicing pad work, but it was said that the sessions started with a 5 min warm-up period before nine 2 min rounds of pad work with 1 min of shadow boxing between rounds. Throughout the sessions subjects wore 0.310 kg (11 oz) gloves and a facemask connected to a metabolic system at all time and they could only remove the mask for the 1-min water breaks at the 20, 40 and 50th min. From the VO_2 kinetics of the whole session for one subject, it can be observed that VO_2 is relatively similar for all types of boxing exercises (pad work, medium bag, heavy bag) while it was obviously lower during the 1-min shadow boxing between rounds although the authors didn't make any statement or statistical analysis concerning such interpretation. For that subject, the VO_2 at the end of the rounds was about 28% higher than the average value for the whole training session. However, they reported an average cost of 2821±190 $kJ \cdot h^{-1}$ for the whole 1-h training session for 8 male subjects (30±4 yr, 177.5±3.5 cm, 78±5.4 kg) accustomed to noncontact boxing training. Knowing the average body weight of the subjects, that corresponds to a VO_2 cost of 28.8±1.93 $ml \cdot kg^{-1} \cdot min^{-1}$, a value that includes the less intense 1-min periods of shadow boxing between rounds. Assuming a similar 28% higher cost for end of rounds values for all subjects, that yields an estimated VO_2 around 36.9±2.5 $ml \cdot kg^{-1} \cdot min^{-1}$ for all boxing exercises, including pad work. This value is slightly lower than the other reported value for pad work (65).

The fact that the subject is not an actual boxer might have affected the metabolic requirements of that exercise, but there is no way to confirm that without further research.

Finally, there is no true reason to believe that the measuring techniques used to assess VO_2 in these articles affected their metabolic requirements. However, it is possible that the measuring devices do not permit certain movements such as rapid body twisting, ample movements or some pivots that are often done along with pad work. In such conditions, it is believed that the use of techniques free from any annoying measuring apparatus would be preferable. Otherwise the techniques might modify the usual motions of boxers and consequently affect their metabolic requirements.

4.3.4 Conclusion

Unfortunately, once again there is an obvious lack of data available on the metabolic requirements of pad work and the few reported articles offered an incomplete representation of this exercise. For example, some important methodological details were not specified and in addition sometimes they measured the requirements of pad work as a part of a continuous training session without according any rest periods between rounds or exercises. For such reasons, it is difficult to fully understand or discuss how pad work was studied and to determine if those values represent typical pad work values for some specific method of practicing this exercise. But realistically, it could be supposed that the reported values might be inferior to what they would usually be since the exercises were not isolated and appropriate rest periods were not allowed and therefore subjects must of either paced themselves or experienced some fatigue that could have affected their performance.

However, with these limitations taken into consideration, those values can still serve as interesting general estimates for this exercise. It appears that approximately 40-50 $ml \cdot kg^{-1} \cdot min^{-1}$ are required for such athletes. But again further research using different routines of pad work with known characteristics (frequency and percentage of types of punches…) would be welcomed to obtain a better idea of the energy cost of that activity.

4.4 Metabolic Requirements of Punching Bag

4.4.1 Description of Punching Bag

Punching a heavy bag or similar equipment is common practice in the sport of boxing probably because of its accessibility and ease of use that conveniently allows boxers to simulate certain aspects of fighting. To practice this exercise, basically all that is needed is hand protection, typically hand wraps with a pair of gloves, and a punching bag that can vary in weight and dimension. Usually, when this exercise is discussed without any extra given details, the punching bag is a fairly tall and heavy bag that is hanging freely and the boxer can easily move around it. Although fundamentally this exercise is quite simple to execute, technically there are still a variety of ways of punching the bag and generally the 2 main categories are: 1) freely, without any assistance or any given details on how to punch the bag and 2) controlled or imposed, with specific or general information on the exercise conditions (intensity, cadence, types of punches, combinations, footwork or not, with or without a trainer or other boxers…). Since the sum of those 2 general categories result to an indefinite amount of possibilities that can require different metabolic requirements, when discussing punching bag it is important to specify how the exercise was done in order to better understand the results and what they represent.

4.4.2 Limitations of the Metabolic Measures for Punching Bag

Since the boxer is usually not at risk of getting hit during this exercise, wearing a facemask or different measuring apparatus is usually not a problem. However, if the facemask is connected to an immobile metabolic system or if the measuring apparatus offers some kind of physical constraint, it might become a limiting factor. In those situations, it may be more practical to have a portable VO_2 system or possibly even use an indirect method to estimate the VO_2 requirements. On the other hand, if the exercise is performed in a more settled way without any footwork, being connected directly to an immobile metabolic system might not limit the boxer from his usual functioning. Therefore adapting the measuring technique to the exercise is of primary importance. On the other hand, unlike VO_2, HR, [LA] and RPE measures are not a constraint to the normal functioning of this exercise.

4.4.3 Metabolic Requirements of Punching Bag

In Czech Republic (73,74), meteorological balloons were used to measure the VO_2 for 1-min of punching bag freely on 15 male boxers (17.5±1.6 yr, 171.7±5.7 cm, 63.3±10.8 kg) of level 1 and 2 performance classes, and VO_2 values that reached 27.0±4.2 $ml \cdot kg^{-1} \cdot min^{-1}$ were reported. From the displayed photo, the bottom of the bag was approximately at shoulder height, which is quite high and also the punching bag seemed to be lighter and smaller then normally. In America (3,4), both versions of physical activity compendiums reported a value of 21.0 $ml \cdot kg^{-1} \cdot min^{-1}$ (6 METs) for punching bag without specifying any methodological detail. In New Zealand (66), another but more recent compendium reported a value of 18.9 $ml \cdot kg^{-1} \cdot min^{-1}$ (5.4 METs). In Japan (65), the same study that measured VO_2 requirements of sparring and pad work with the same group of 6 college boxers (19.7±0.8 yr, 165.8±5.2 cm, 57.9±4.2 kg) reported a variety of results depending on the technique used to determine VO_2 (portable system or HR/VO_2 regressions). The specific method in which punching bag was done is still unknown and so is the exact duration that the exercise lasted. But punching the bag was done as a part of the same continuous ~1 or 2 hour long training session and it was measured after ~30 min of warming up, shadow boxing, sparring and pad work, and lasted approximately 5 to 10 min for the Douglas bag technique and after ~50 min of warming up, shadow boxing, sparring and pad work, and lasted ~5 min period for the HR/VO_2 regression technique with unknown work-rest ratios. When measured with Douglas bags, peak values of 52.5±7.1 $ml \cdot kg^{-1} \cdot min^{-1}$ were reported which represents, 102.7 %VO_2max. On the other hand, when VO_2 was estimated from HR/VO_2 regressions, different VO_2 values of 49.1±6.7, 45.3±5.7 and 52.3±6.7 using treadmill, ergocycle or with basic boxing motions HR/VO_2 individual regressions, respectively. Those values correspond to 96.1, 88.6 and 102.3 %VO_2max. It is not known if these values are peak or average values. No HR values were reported for that exercise.

Instead of studying free punching bag, some studies imposed a standardized way to do it. For instance, in America (1), a group of 10 subjects (males: n = 5, 27.0±4.0 yr and females: n = 5, 29±7.0 yr) with no history of formal boxing training participated in a controlled punching bag session where they had to punch with moderate force a 100 lb (45.4 kg) heavy bag with 0.23 kg (8 oz) gloves at the cadence of 2 punches per second for 5 min. Throughout the session, the subjects were connected to a TEEM 100 metabolic system and they were instructed to keep their feet planted to the ground while hip movement was allowed. A mean value for the whole group of 22.9±10.0 ml·kg^{-1}·min^{-1} was reported with a surprising wide range from 8.4 to 39.4 ml·kg^{-1}·min^{-1}. In another American study (67), 16 subjects (males: n = 7, 23.4±11.0 yr and females: n = 9, 33.0±9.2 yr) with boxing experience ranging from none to amateur boxing had to punch a 110 lb (49.9 kg) heavy bag while wearing 0.09 kg (3 oz) bag gloves for 3 min. Throughout the session, subjects were connected to a metabolic cart and they were instructed to punch singularly or in combinations with the addition of lower body movements (lunges, lateral movement and shuffling) to a cadency of 134 b·min^{-1}. A mean value for the whole group of 31.5±6.9 ml·kg^{-1}·min^{-1} was reported. Always in America (56), 18 fitness boxers (males n = 12 & females n = 6: 22.0±2.8 yr, 170.8±7.7 cm, 71.5±12.6 kg) used a pair of 0.34 kg (12 oz) gloves to punch a SLAMMAN, which is a kind of dummy standing on the ground, at an imposed cadencies of 60, 72, 84, 96, 108, 120 b·min^{-1} for 2 min rounds. Between each round subjects had to sit down till their HR was within 10 b·min^{-1} of their warm-up recovery HR. During the rounds they were connected to a metabolic cart and had to punch at the beat of a metronome with alternating right and left punches of their choice while seemingly standing still on their feet. Similar VO_2 values of approximately 27.0-30.0 ml·kg^{-1}·min^{-1} were reported regardless of the punching frequency. In addition, the same group of researchers (88) had previously published a very similar abstract where they seemed to have compared the same 12 subjects in 2 groups of 6 trained (23.5±4.4 yr, 173.3±7.8 cm, 76.2±14.2 kg) and 6 untrained (21.2±0.9 yr, 173.0±7.2 cm, 78.3±8.0 kg) male boxers that went through the same testing protocol. Unfortunately they did not report the VO_2 values for punching the bag, but they did mention that the results were not significantly different between both groups and that their experience was not an influencing factor on the VO_2 requirements during this exercise.

From the articles quoted above while describing the VO_2 of free punching bag, HR values were sometimes reported with values that reached 148.1±14.0 b·min^{-1} for a 1 min round without specifying HRmax (73,74), and peak values of 179.0±10.0 b·min^{-1} which represent 93.2 %HRmax for the Douglas bag technique (65). To our knowledge, no extra HR, [LA] or RPE data is available for punching the bag freely.

For controlled or imposed punching bag exercise, HR values of 158.0±21.0 b·min^{-1} for punching the bag at 2 punches per second for 5 min (1) and 160.3±12.0 b·min^{-1} for a punching and lower body movement cadency of 134 b·min^{-1} (67) were reported, without reporting HRmax. One more study reported continuously increasing values between ~167 and 183 b·min^{-1} for punching frequencies of 60 to 120 b·min^{-1}, which represents ~85 to 93 %HRmax while VO_2 cost was relatively similar at all frequencies (56). Other articles found in the literature offered a range of average HR values from ~165 to 195 b·min^{-1} for actual boxers doing a variety of methods (9,61,84). No study reporting VO_2 also reported [LA] values, however, other articles reported values of ~4 to 13 mmol·L^{-1} measured at various times for real boxers doing a variety of methods (9,61,84). As for RPE, values of 13.3 (1) for 2 punches per second for 5 min, 15.1±1.4 for punches and lower body movement at a cadence of 134 b·min^{-1} (67) and a continuous increase between ~12 and 15 for frequencies of 60 to 120 b·min^{-1} (56) were reported on a 6-20 Borg Scale. To our knowledge, no other studies were available in the literature on RPE for controlled or imposed punching bag.

Reported VO_2 cost, HR, [LA] and RPE values for free or standardized punching bag showed large differences. That may be due to large differences in the methodologies used in each studies (including method of measuring VO_2 as well as duration of the exercise and, even in “standardized” studies, the impossibility to control the power of the punches). Thus, it is hardly possible to establish a representative average for the metabolic requirements of punching the bag or to compare the studies on even ground. Instead some general and specific observations will be made.

For example on punching the bag freely, in the two studies that used similar meteorological or Douglas bags measuring techniques it could be supposed that boxers punching the bag for 1 min (73,74), as opposed to a ~5 to 10 min period (65), might exerted themselves more during this exercise. From the results reported however, the opposite is observed (~27 vs. ~53 ml·kg^{-1}·min^{-1}). It might not be appropriate to compare those values per se, because they might not entirely be representative of the actual intensity of the exercises. For example, in the study that measured the exercise for only 1 min, there might not be enough time to reach steady state VO_2 which would underestimates steady state VO_2. Furthermore, if the air was collected in a single balloon, the value obtained would be an average value for that period and not the value at the end of the period, which further underestimates the steady state VO_2 cost of that exercise. It is however difficult to say that the values reported in the other study (65), are more realistic. For instance (65), their reported %VO_2max was higher than the %HRmax, which once again raises suspicions on those values. In compendium articles (3,4,66) low values around 20 $ml\cdot kg^{-1}\cdot min^{-1}$ were reported, but it is hard to conclude anything without precise methodological details. In the studies where the punching bag technique was standardized, the reported range of VO_2 cost from 22.9±10.0 to 31.5±6.9 $ml\cdot kg^{-1}\cdot min^{-1}$ is quite large and could be attributed to the different ways that the technique was standardized (with and without footwork, bag size and weight, gloves, exercise duration, portable equipment…). More interestingly though, when looking at each study individually, the study with the lowest VO_2 values (1), is the one where boxers were instructed to punch with moderate force. Furthermore, such information could be interpreted quite differently between subjects and might explain why they also reported a very wide range from 8.4 to 39.4 $ml\cdot kg^{-1}\cdot min^{-1}$. But nonetheless, since it was for an imposed frequency, those values indicate the influencing potential of punching power on the metabolic requirements. As for the study (67) with the highest reported values (31.5±6.9 $ml\cdot kg^{-1}\cdot min^{-1}$), this time they didn't control the punching power and in addition they also imposed lower body movement. Thus the combination of potentially higher punching power included with lower body movement could explain the higher values. Finally, when the same subjects had to punch at various frequencies (60, 72, 84, 96, 108, 120 $b\cdot min^{-1}$) without any instructions on the punching power, no significant differences was observed between frequencies, which again confirms the importance of the punching power in the VO_2 requirements (56). However and strangely, the HR and RPE continuously increased with the punching frequency, which is unusual. Furthermore, the authors (88) said that for such an isolated exercise when comparing trained and untrained boxers, there was no difference due to the experience level. As for the studies that didn't report any VO_2 values, an increase from round to round for both HR and [LA] was noticed when such information was available (61,84).

Finally for both general categories of punching the bag (free or standardized), there is once again no true reason to believe that the VO_2 measuring techniques used in these articles affected the normal functioning of the exercises or the metabolic requirements per se, but instead what appears to be an issue is the measuring time in which a technique is implicated. When using meteorological balloons or Douglas bags, it is important to know their limitations. For example to report peak values, the sampling time should not be too long (~30 s) but to report average values, the sampling period should be representative of the whole exercise. When comparing the Douglas bag technique to the HR/VO_2 regression (65), no significant differences were obtained between values (52.5±7.1 vs. 52.3±6.7 $ml \cdot kg^{-1} \cdot min^{-1}$), but it is important to consider that it was for different times of effort once again and that it is unknown whether the HR/VO_2 regression are peak or average values (65). But, as these values were obtained for a ~5-min bout during a ~2-h training session and since they represent 102.3 %VO_2max, they probably correspond to peak values rather than average values. When the punching bag exercises were done with the feet planted, there is also no reason to believe that an immobile metabolic system affected the performances of boxers and thus the energy cost of punching the bag in that manner.

4.4.4 Conclusion

Due to variability in the modalities used to train with the punching bag (using fix stance or moving around, types, frequency and power of punches…), the metabolic cost will vary accordingly. It is thus difficult to get a consensus from the literature. We have seen values as low as 18.9 $ml \cdot kg^{-1} \cdot min^{-1}$ and as high as 52.5 $ml \cdot kg^{-1} \cdot min^{-1}$. We might think that a typical hard training bout on the heavy bag might require values in the upper range of reported values knowing it is possible to get a supra maximal workout while punching fast at high power, which, however, is not typical of what boxers are normally doing.

4.5 Conclusion

In summary, as discussed in this section on the energy cost of the various boxing exercises, there are different ways of measuring the metabolic requirements of sparring, pad work and punching bag, and not all of them have the same validity or effectiveness depending the technique of measurement (particularly for VO_2, as opposed to HR, [LA] and RPE) or the way of practicing it. Since the metabolic requirements of boxing exercises are prone to change depending on the type of subjects, the study protocols, the way of practicing the exercises and the measuring techniques, meticulously detailing the methodologies and monitoring the exercises are of primary importance to better understand the results. In addition, when a progressive maximal test is done with the same subjects, it enables possible interpretation of the specific exercise requirements in percentage of maximal values, which makes it even more conclusive.

One of the purposes of this review was to determine the metabolic requirements of each boxing exercise and to compare their levels of requirements to better understand the training load of the boxer. Concerning studies cited in this section, interpreting or comparing the metabolic requirements of these boxing exercises (sparring, pad work and punching bag) does not yield highly conclusive observations. Most studies are inaccurate from a methodological standpoint and do not respect the principles and limitations of metabolic measures described in section 4.1. Furthermore, most studies were investigating only one exercise. Thus, it is not surprising that metabolic requirements are sometimes higher for one exercise and sometimes for another one. In addition when looking at the compilation of data for each exercise individually, visibly sparring was done with many different methodologies and none of them measured VO_2 of true sparring, pad work had insufficient data reported and the punching bag exercises and objectives varied quite extensively between articles. But with those limitations taken into consideration, we can observe that reported values were around; a minimum of 25 $ml \cdot kg^{-1} \cdot min^{-1}$, an average of 40 $ml \cdot kg^{-1} \cdot min^{-1}$ and a peak of 50 $ml \cdot kg^{-1} \cdot min^{-1}$ or higher for sparring, average or peak values around 40-50 $ml \cdot kg^{-1} \cdot min^{-1}$ for pad work and once again average or peak values between 20-50 $ml \cdot kg^{-1} \cdot min^{-1}$ and 20-30 $ml \cdot kg^{-1} \cdot min^{-1}$ for punching the bag freely and in a controlled or imposed way, respectively. Furthermore, the one study to measure all 3 boxing exercises (65) reported peak VO_2 values of 48.2±3.8 and 52.5±7.1 $ml \cdot kg^{-1} \cdot min^{-1}$, which represent 94.3 and 102.7 %VO_2max for pad work and punching bag, respectively and average or peak values of around 56, 42.7±3.3 and 52.3±6.7 $ml \cdot kg^{-1} \cdot min^{-1}$ which represent 108, 83.6 and 102.3 %VO_2max for sparring, pad work and punching bag, respectively. It seems that boxing exercises when done as a somewhat hard workout require similar levels of energy expenditure and could be quite demanding. But still, further research is needed to get a proper and conclusive comparison of the metabolic requirements of various boxing exercises.

5.0 GENERAL CONCLUSION

The first goal of this review was to gather all available articles on the aerobic fitness of boxers and the metabolic requirements of boxing exercises such as sparring, pad work and punching bag and to attempt to describe their methodologies and results. That objective has been accomplished by doing the biggest review to date on the subject, which to our knowledge also happens to be the only one of its kind. The second objective was to not only report the data, but to try to determine the aerobic fitness of boxers and the metabolic requirements of each exercise and to compare them afterwards. However, due to the vast amount of variability and discrepancy found in the methodologies and the results of most articles, it made that task quite complicated.

As a final word, this review has allowed the discovery of several studies from many different sources with numerous methodological shortcomings. More often than not, these studies were limited to the study of a single boxing exercise and none really measured the VO_2 of "true" sparring, i.e., with punches to the face and without any motion hindrance due to the measuring apparatus. As observed in this review, determining the VO_2 requirement of true sparring appears as a major issue for boxing. Much more work remains to be done with hopefully better methods, particularly to measure "true" sparring.

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PART II: EXPERIMENTAL STUDY

Title: **VO_2 requirements of boxing exercises.**

Running title: **Energy cost of boxing.**

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Implication of authors:

Eric Arseneau is the principal investigator of this study realized under the direction of professor Luc Léger, in a school context to obtain a master's degree (M. Sc.). Mr. Saïd Mekary, is a student colleague, who has participated as an assistant in the development of the measuring protocol of session 3 of the experimental study and the collection of its measures.

1.0 ABSTRACT

The purpose of this study was to quantify the physiological requirements of various boxing exercises such as sparring, pad work and punching bag. Since it was not possible to measure the oxygen uptake (VO_2) of "true" sparring with a collecting gas valve in the face, we developed and validated a method to measure VO_2 of "true" sparring based on "post-exercise" measurements. Nine experienced male amateur boxers (Mean±SD: age = 22.0±3.5 yr, height = 176.0±8.0 cm, weight = 71.4±10.9 kg, number of fights = 13.0±9.5) of regional and provincial level volunteered to participate to 3 testing sessions: 1) maximal treadmill test in the LAB 2) standardized boxing training in the GYM and 3) standardized boxing exercises in the LAB. Measures of VO_2, heart rate (HR), blood lactate concentration [LA], rated perceived exertion level (RPE) and punching frequencies were collected. VO_2 values of 43.4±5.9, 41.1±5.1, 24.7±6.1, 30.4±5.8 and 38.3±6.5 $ml \cdot kg^{-1} \cdot min^{-1}$ were obtained, which represent 69.7±8.0, 66.1±8.0, 39.8±10.4, 48.8±8.5 and 61.7±10.3 $\%VO_2$peak for sparring, pad work and punching bag at 60, 120 and 180 $b \cdot min^{-1}$, respectively. Except for lower VO_2 values for punching the bag at 60 and 120 $b \cdot min^{-1}$ ($p<0.05$), there was no VO_2 difference between exercises. Similar pattern was obtained for %HRmax with respective values of 85.5±5.9, 83.6±6.3, 67.5±3.5, 74.8±5.9 and 83.0±6.0. Finally, sparring %HRmax and [LA] were slightly higher in the GYM (91.7±4.3 & 9.4±2.2 $mmol \cdot L^{-1}$) vs. LAB (85.5±5.9 & 6.1±2.3 $mmol \cdot L^{-1}$). Thus, in this study simulated LAB sparring and pad work required similar VO_2 (43-41 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively), which corresponds to ~70 $\%VO_2$peak. These results underline the importance of a minimum of aerobic fitness for boxers and draw some guidelines for the intensity of training.

Key Words: Energy cost, Physiological demand, Heart rate, Sparring, Pad work, Punching bag.

2.0 INTRODUCTION

Boxing, also known as the "sweet science", has ironically very little scientific evidence concerning its physiological requirements (14). Therefore boxers mostly rely on empirical approaches. For a majority of boxers, training methods are established by trials and errors after numerous practices with their boxing team. Of course, this lack of tangible guidelines makes it difficult to determine if the training methods utilised are optimal for the physiological requirements of competitions. Consequently, the margin of progress and chances of success at the highest level become limited. As a result, it can be discouraging and possibly lead to premature withdrawal or amplify the risk of injuries or failures. The few studies that were found on the physiological requirements of boxing used various methodologies and often reported different results. Measures such as heart rate (HR) and blood lactate concentration [LA] are easy to obtain and have been reported several times (1,7,8,9,12,13,17,18,20,24,25). In general, HR values around 170-180 $b \cdot min^{-1}$ are reported for sparring (7,8,9,12,18,24,25) and ~167 $b \cdot min^{-1}$ for pad work (18), while a wider range between 145-195 $b \cdot min^{-1}$ is observed for the punching bag (1,13,17,18,20,24,25). For [LA], values around 9-12 $mmol \cdot L^{-1}$ are reported after 3 rounds of sparring (8,12) or punching bag (17). On the other hand, oxygen uptake (VO_2) during "true" sparring or other boxing exercises is difficult to measure and reported values are controversial (see below). Reinvestigating the VO_2 cost of boxing exercises is thus the focus of this study.

Concerning sparring, Seliger (24,25) reported higher VO_2 values of 38.9±5.9 $ml \cdot kg^{-1} \cdot min^{-1}$ (Mean±SD) than the ones obtained for the punching bag using the same subjects and similar methodology. In their compendiums, Durnin (11) reported values of at least 21.8 and 23.1 $ml \cdot kg^{-1} \cdot min^{-1}$ or higher for females and males, respectively, while Ainsworth et al. (2,3) reported values of 31.5 and 42.0 $ml \cdot kg^{-1} \cdot min^{-1}$ for sparring and "in ring general" [*sic*], respectively. In a review paper, Ostyn et al. (21) reported a VO_2 range of 26.3-42.0 $ml \cdot kg^{-1} \cdot min^{-1}$. More recently using the treadmill HR/VO_2 regression approach, Chatterjee et al. (7,8,9) reported higher mean values from 40.3±7.0 to 46.6±6.6 $ml \cdot kg^{-1} \cdot min^{-1}$ with peak values between 45.9±6.0 to 50.5±7.9 $ml \cdot kg^{-1} \cdot min^{-1}$ from round 1 to round 3 (2-min rounds) for women sparring.

Another typical boxing exercise is "pad work", which is punching on a partner's pads or mitts. In their study, Morita et al. (18) reported values of 48.2±3.8 $ml \cdot kg^{-1} \cdot min^{-1}$.

More recently for similar exercise with Muay Thai Boxing, Crisafulli et al. (10) reported values of 42.5±2.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (average for three 3-min rounds) for pad work involving fists, elbows, knees and feet to strike and block.

For the punching bag (heavy bag), Seliger (24,25) reported values of 27.0±4.2 $ml \cdot kg^{-1} \cdot min^{-1}$ using meteorological balloons to measure VO_2. About 15 years later and using Douglas bags, Morita et al. (18) reported very high VO_2peak values of 52.5±7.1 $ml \cdot kg^{-1} \cdot min^{-1}$, which was superior to the VO_2max of their subjects. In their compendiums (no methodological details), Ainsworth et al. (2,3) and Moy et al. (19) reported lower values of 21.0 and 18.9 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. Adams et al. (1) reported VO_2 costs of 22.9±10.0 $ml \cdot kg^{-1} \cdot min^{-1}$ for punching at 120 $b \cdot min^{-1}$ while young adult male and female boxers (n=5+5) were continuously connected to a metabolic system without any foot work. Two years later, O'Driscoll et al. (20) did a similar study and reported higher VO_2 costs of 31.5±6.9 $ml \cdot kg^{-1} \cdot min^{-1}$ for a higher synchronised pace of 134 $b \cdot min^{-1}$ for "punches and lower body movements" [*sic*] while young adult male and female boxers (n=7+9) were also continuously connected to a metabolic system. Recently, Kravitz et al. (13) established the VO_2 cost of punching at 6 different frequencies (60-120 $b \cdot min^{-1}$) with fitness boxing subjects hitting a SLAMMAN (Fitness Quest, Canton, OH, USA), which is a type of dummy standing on the floor instead of a regular hanging punching bag and they reported almost similar VO_2 values of ~27.0-30.0 $ml \cdot kg^{-1} \cdot min^{-1}$ regardless of the punching frequency.

As we can see, the energy cost of boxing exercises varies a lot depending on the type of subjects, the methodology used to estimate VO_2 cost and according to the type of boxing exercises. For sparring, previous studies used hindering equipment (collecting gas valve in the face and portable VO_2 systems) or estimated VO_2 from HR/VO_2 regression which is not a very accurate procedure (18). In an attempt to solve these problems and to enable proper comparisons, we reinvestigated the energy cost of key boxing exercises such as sparring, pad work and punching bag with a new method to measure VO_2 without hindering the boxers movement. Furthermore, since these measurements were obtained in the LAB we wanted to know whether the sparring intensity in the LAB and in the GYM was similar. This was done by comparing the HR, [LA], rated perceived exertion (RPE) and punching frequency of sparring in the GYM and in the LAB. A final objective was to study the effect of punching frequency on the VO_2 cost of the punching bag. To our knowledge, this study is unique because it is the only one that measures VO_2 of "true" sparring without any motion hindrance. It is also the sole study investigating the effect of punching frequency on the energy cost of punching the bag with experienced boxers. Knowing accurate VO_2 requirements is important to properly adjust the training load of boxers.

3.0 METHODS

3.1 Experimental Approach to the Problem

In order to fulfill our objectives, subjects participated in 3 testing sessions: 1) maximal treadmill test in the LAB, 2) standardized boxing training in the GYM 3) and standardized boxing exercises in the LAB. Three 2-min rounds of various boxing exercises with 1-min rest in between were used as the independent variables. In the GYM, these exercises were sparring and free punching bag and in the LAB, they were sparring, pad work and cadence controlled punching bag with alternating straight punches only, without any foot work. The timing of dependent variables (VO_2, HR, [LA], RPE, and video recording of punching frequency) is illustrated in Figure 1 and detailed thereafter. A minimum of 1 day was required between 2 sessions and all sessions were done within a 3-month span.

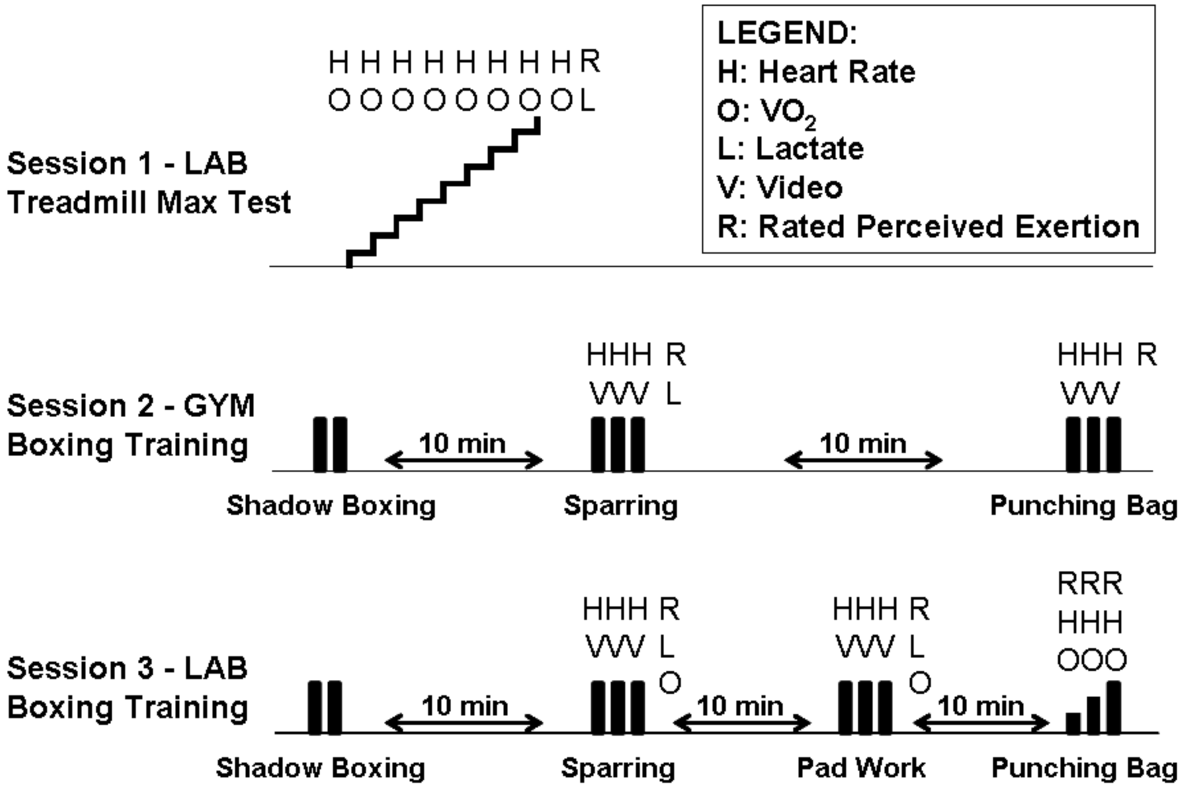

Figure 1. Experimental scheme: dependent variables and their timing for each experimental session.

3.2 Subjects

Nine experienced male amateur boxers (age = 22.0±3.5 yr, height = 176.0±8.0 cm, weight = 71.4±10.9 kg, number of fights = 13.0±9.5) of regional and provincial level volunteered to participate to this study (Table 1). All owned a competition passport licensed by the Canadian Amateur Boxing Association and provided written consent. The study protocol was approved by the Ethics Committee of University of Montreal.

	Age	Weight	Height	VO_2peak	HRmax	[LA]max	Experience
	yr	kg	cm	$ml \cdot kg^{-1} \cdot min^{-1}$	$b \cdot min^{-1}$	$mmol \cdot L^{-1}$	fight
Mean	22.0	71.4	176.0	62.2	194.9	10.0	13.0
SD	3.5	10.9	8.0	4.1	11.8	2.8	9.5
Minimum	17.0	56.8	164.0	53.6	177.0	5.0	2.0
Maximum	29.0	91.8	189.0	66.2	207.0	14.0	31.0

Table 1. Biometrics and maximal treadmill values of subjects (n = 9)

3.3 Procedures

*Session 1. Maximal treadmill test in the LAB***.** Prior to the treadmill test, height and weight were measured without shoes. For the treadmill (Q65, model 645, Quinton Instruments Co., Bothell, WA, USA) protocol, subjects warmed up for 3 min at 8 $km \cdot h^{-1}$ and 0 % slope. Thereafter, speed increased by 1 $km \cdot h^{-1}$ every 2 min till exhaustion (15). The objective was to determine the VO_2peak, HRmax, [LA]max and RPEmax of boxers. Temperature and relative humidity were around 21ºC and 35%.

Session 2. Standardized boxing training in the GYM. The 2nd session took place in the respective boxing GYM of each boxer and the goal was to simulate a typical boxing training session including 3 sequences of typical exercises: shadow boxing (2 rounds), sparring (3 rounds on a ~4.9 by 4.9 m (~16 x 16 ft) competition ring) and freely hitting a punching bag (3 rounds) weighing around 34.0 kg (75.0 lb) depending on the gym. A 10-min rest was given between each exercise and used to put on a headgear, a jock strap, a pair of gloves and a mouth piece for the sparring. Rounds were of 2-min duration with 1-min standing rest in between. Subjects wore hand wraps for the 3 exercises and 0.45 kg (16 oz) gloves for sparring and punching the bag. Each boxer wore his customary boxing gear and was informed of the procedure beforehand. Subjects were randomly paired and instructed to perform as they usually would during these exercises. RPE was measured after the 3rd round of sparring and punching bag exercise; and [LA] was recorded at the end of the 3rd round of sparring only. For the whole GYM session, HR was continuously monitored. Sparring and punching bag rounds were videotaped in order to count the number and frequency of punches thrown. Temperature and relative humidity were not measured but subjectively, were relatively constant and similar to LAB conditions.

Session 3. Standardized boxing exercises in the LAB. During the 3rd testing session, simulated boxing exercises such as shadow boxing (2 rounds), sparring (3 rounds), pad work (3 rounds) and punching bag (3 rounds) were performed in the LAB. Boxing gear, round duration, rest period between exercises and rounds were the same as in session 2. Exercises were done on a 4.3 by 4.3 m (14 x 14 ft) free space without ropes. Sparring was a simulation of the sparring done in the GYM. For the pad work (new exercise), subjects had to hit the partner's pads in a pre-determined routine of 4 different combinations that were always repeated in the same order till the end of the rounds with a few movements of light footwork in between combinations. For the right-handed boxers, the combinations consisted of 1) jab, jab, straight right, 2) jab, straight right, left hook, straight right, 3) jab, straight right, jab, straight right, and 4) right uppercut, left uppercut, straight right and left hook. For the sole left-handed boxer, left and right punches were reversed. Approximately 30 s of the 1st round was needed by the subjects to get familiar with the combinations and afterwards they would hold a steady rate. For the punching bag rounds, subjects had to hit a 25 kg (55 lb) bag held motionless by an assistant in a normalized way. They were asked to stand an arm length from the punching bag with their feet stationary at the width of their shoulders while hitting the bag alternating with jabs and straight rights from chin to bag at the beat of a metronome. Rounds 1, 2 and 3 were done at 60, 120 and 180 $b \cdot min^{-1}$, respectively.

As for the GYM, the whole session was videotaped and the HR data were continuously collected. Temperature and relative humidity were around 21ºC and 37%. RPE was obtained at the end of sparring, pad work and after each punching bag round. In addition, VO_2 was measured at the end of the 3rd round of sparring and pad work and continuously during each round of punching bag. [LA] was measured at the end of the sparring and pad work only. For sparring and pad work, boxers were connected to the mouth piece of our metabolic system immediately after the 3rd round. The system was located about 2 m away from the boxing ring. The whole procedure took about 3-5 s, including nose-clip fixation. Once connected to the metabolic system, the subjects were asked to exert themselves at the same intensity as before, by continuing foot work and punching on the gloves or pads of his partner in order to minimize the recovery process for 60-75 s to give time to the metabolic system to reach an equilibrium value. Only equilibrium values were retained as the VO_2 cost of the activity. The calibration of the metabolic system was completed about 5-10 min before the 1st round of sparring.

That approach to measure post-exercise VO_2 was validated with another group of 9 subjects using similar “rounds” of treadmill exercise, in order to enable VO_2 measures during the exercise and post-exercise phases. VO_2 obtained during treadmill exercise was used as our gold standard to assess the accuracy of VO_2 measured after reconnecting the subjects at the end of a “round” of running (Annex 1). In summary, VO_2 values obtained at 3 different intensities on the treadmill between 30 to 75 s after the reconnection of the subjects were similar to the values obtained during steady state exercise (2-way analysis of variance [ANOVA] for repeated measures and Tukey a posteriori tests (n.s., $p>0.05$) and regression analysis: $r = 0.96$, SEE = 1.6 $ml \cdot kg^{-1} \cdot min^{-1}$).

Figure 1 describes the kinetics of dependant variables measured for the 3 sessions and also indicates potential direct comparisons of boxing exercises for each variable.

3.4 Measuring Apparatus and Tests

For VO_2 measures, expired gases passed through an open circuit and were analyzed in real time by an automated and computerized system (Moxus Modular Metabolic System, AEI Technologies, Naperville, IL, USA) (5). Results were averaged every 30 s for the maximal treadmill test and every 15 s for the simulated boxing exercises in the LAB. HR was measured throughout every session with a Polar S810 HR monitor. Data was recorded every 5 s and later transferred on a computer to be analyzed (Polar Electro, Kempele, Finland). HR measured with the Polar S810 is very reliable (16). RPE was recorded after every exercise using the Borg scale (6) with scores ranging from 6 to 20 (very, very light to very, very hard). Finally as a witness of the anaerobic solicitation, [LA] was measured from a fingertip blood sample taken 4 min after the 3rd round of the exercise. The blood sample was analyzed with the Lactate Pro (ARKRAY, Inc., Kyoto, Japan), which has been reported valid (22,23).

3.5 Statistical Analyses

Four 2-way (round and boxing exercise) ANOVA for repeated measures with Tukey a posteriori tests were used to describe and compare %HRmax and punching frequency of each round of sparring and punching bag in the GYM (Figure 2) and sparring and pad work in the LAB (Figure 3). Six 1-way ANOVA were used to compare average or peak VO_2, $\%VO_2$peak, %HR, [LA], RPE and punching frequency values of the 3 rounds combined for all possible boxing exercises whether they were done in the GYM or in the LAB (Table 2 and Figure 4). First degree Pearson correlation and standard error of the estimate between VO_2 cost of sparring as the dependent variable and body weight and VO_2peak as the independent variables were also computed to see a possible effect of these 2 variables on VO_2 cost of sparring. Unless otherwise stated, all reported differences are significant at the $p \leq 0.05$ level. Analyses were performed with or without missing data being replaced, giving exactly the same results. Thus only results with missing data being replaced are reported (n = 9). Mean±SD format is used in the text.

4.0 RESULTS

4.1 GYM vs. LAB

Sparring was the sole exercise being studied both in the GYM and LAB in the same conditions (Table 2) and it was found that %HRmax and [LA] were higher ($p<0.05$) in the natural GYM environment (91.7±4.3 & 85.5±5.9 and 9.4±2.2 & 6.1±2.3 $mmol \cdot L^{-1}$) while RPE and punching frequency were similar. Note that these %HRmax and punching frequency values represent the average of 3 rounds while RPE and [LA] were only taken at the end of last round. VO_2, %HRmax and RPE obtained for multistage treadmill test, sparring, pad work and punching the bag at different frequencies (60, 120 and 180 $b \cdot min^{-1}$) in the LAB are also illustrated in Figure 4 as well as %HR and RPE for sparring and free punching bag in the GYM.

	HR	[LA]	RPE	Punching	VO_2	VO_2
	%HRmax	$mmol \cdot L^{-1}$	6-20 Scale	$b \cdot min^{-1}$	$\%VO_2peak$	$ml \cdot kg^{-1} \cdot min^{-1}$
GYM						
Sparring	91.7±4.3	9.4±2.2	12.9±1.8	35.7±9.9	NA	NA
Punching Bag	86.9±5.7	NA	12.6±1.9	70.6±22.6	NA	NA
Significance	0.005	--	n. s.	0.003	--	--
LAB						
Sparring	85.5±5.9	6.1±2.3	12.2±1.3	34.9±7.1	69.7±8.0	43.4±5.9
Pad Work	83.6±6.3	4.0±1.7	13.6±2.1	61.4±7.9	66.1±8.0	41.1±5.1
Significance	n. s.	n.s.	n. s.	0.000	n. s.	n. s.
GYM vs. LAB (Sparring)						
Significance	0.006	0.018	n. s.	n. s.	--	--

Mean±SD (n = 9)

Table 2. Various comparisons: Sparring vs. Punching bag (GYM), Sparring vs. Pad work (LAB) and GYM vs. LAB (Sparring) for %HRmax (mean of 3 rounds), [LA], RPE, punching frequency (mean of 3 rounds) and VO_2.

4.2 Round Effects

In the GYM, only HR and punching frequency were recorded from round to round. %HRmax increased ($p<0.05$) from round to round for sparring and punching bag (Figure 2). For the punching frequency however, it increased ($p<0.05$) only for the punching bag (Figure 2). For each round, %HRmax was higher for sparring (vs. punching bag, $p<0.05$), while punching frequency was higher on the punching bag (vs. sparring, $p<0.05$).

In the LAB, %HRmax increased only from round 1 to round 2 for sparring and pad work ($p<0.05$) while the punching frequency increased from round 1 to round 2 for pad work only ($p<0.05$) (Figure 3). No pad work exercise was performed in the GYM to allow similar comparison. In the LAB, punching the bag was done at increasing imposed frequency from round 1 to round 3 and %HRmax and punching frequency obviously increased ($p<0.05$). %HRmax was higher for sparring (vs. pad work, $p<0.05$) in round 1 only while punching frequency was higher for each round for pad work ($p<0.05$).

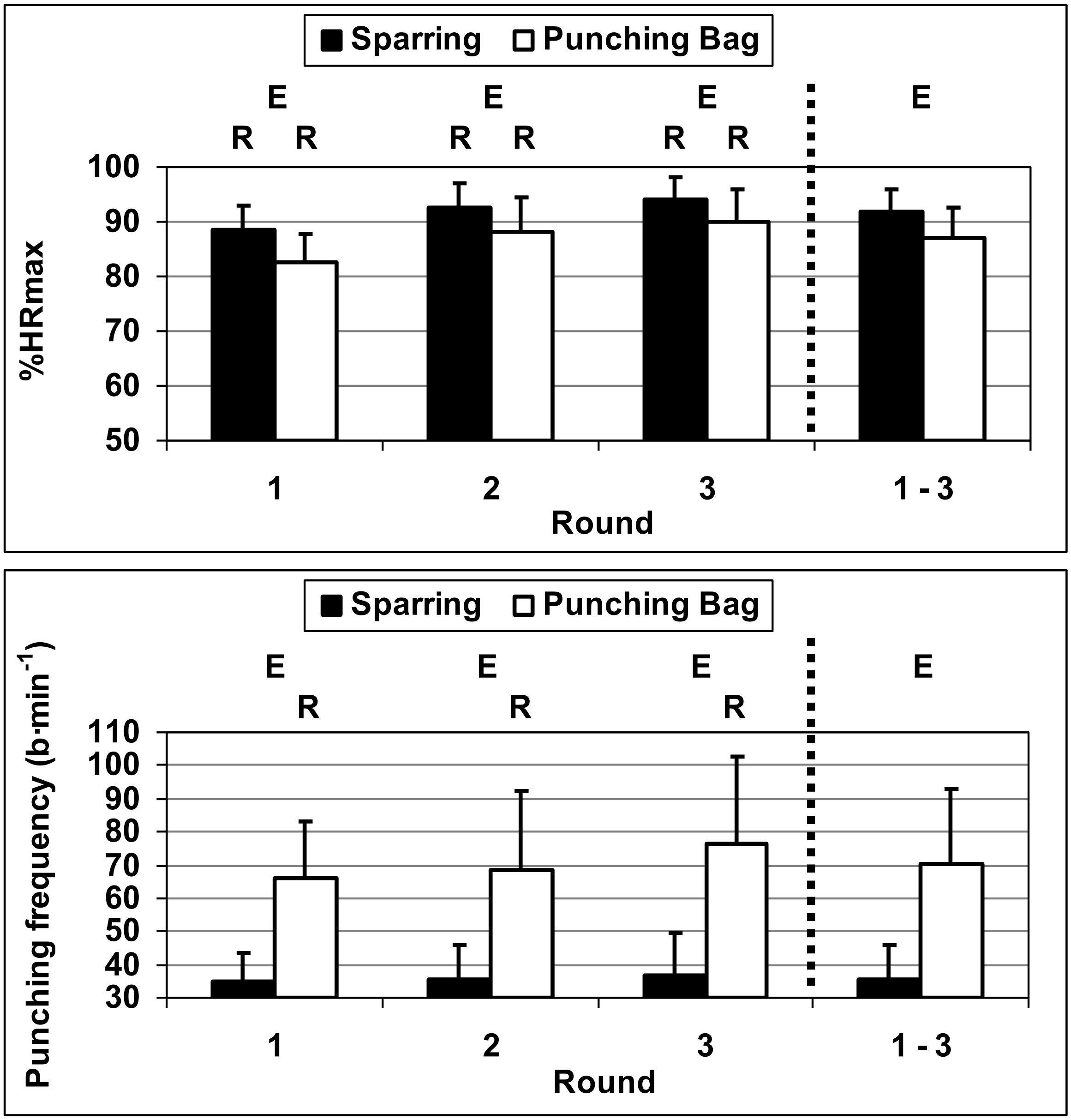

Figure 2. Round effects in the GYM for %HRmax (upper graph) and punching frequency (lower graph) during sparring and punching bag (Mean±SD). R and E indicates round by round and exercise effects, respectively ($p<0.05$). Right end bar is the mean of the 3 rounds.

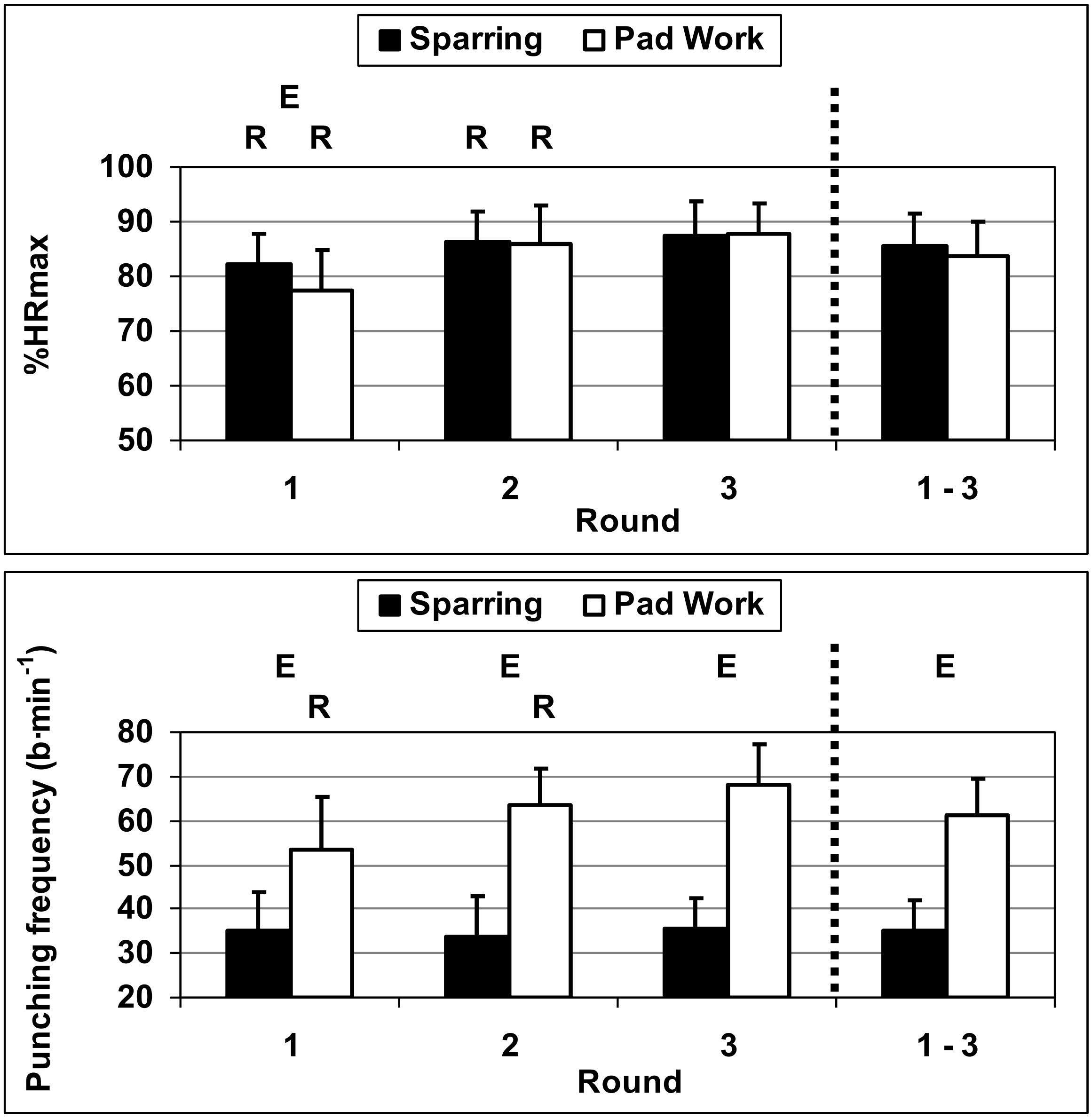

Figure 3. Round effects in the LAB for %HRmax (upper graph) and punching frequency (lower graph) during sparring and pad work (Mean±SD). R and E indicates round by round and exercise effects, respectively ($p<0.05$). Right end bar is the mean of the 3 rounds.

4.3 Exercise Effects

Since GYM and LAB results were different ($p<0.05$) for %HRmax and [LA] and since different exercises were done in each location, exercise effects are reported separately in each location (Table 2 and Figure 4).

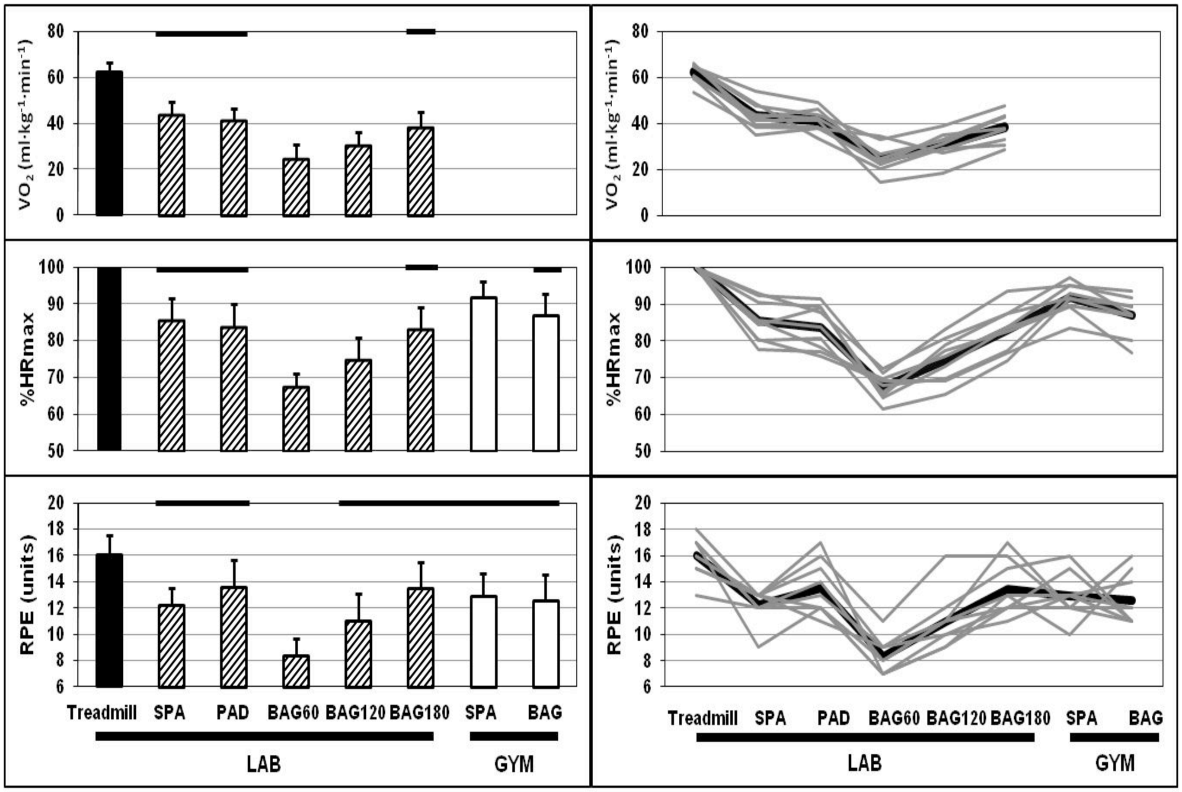

Figure 4. VO_2, %HRmax and RPE obtained for multistage treadmill test, sparring (SPA), pad work (PAD) and punching bag at different frequencies (BAG 60, 120 and 180 $b \cdot min^{-1}$) in the LAB. %HR and RPE for sparring and free punching bag in the GYM are also illustrated. Left panel: Mean and standard deviation values covered by a same level horizontal bar are not significant ($p>0.05$). Right panel: variability of individual values.

In the GYM, concerning %HRmax and punching frequency (Table 2), %HRmax was higher for sparring than for punching bag (91.7±4.3 & 86.9±5.7, $p<0.05$), but it was the opposite for punching frequency (35.7±9.9 & 70.6±22.6 $b \cdot min^{-1}$, $p<0.05$). The same was true for each round (Figure 2). In the LAB (Table 2), %HRmax was similar for sparring and pad work (85.5±5.9 & 83.6±6.3), except for round 1 (Sparring > Pad, $p<0.05$ Figure 3), while punching frequency was higher for pad work than sparring (61.4±7.9 & 34.9±7.1 $b \cdot min^{-1}$, $p<0.05$). No free punching bag exercise was performed in the LAB to allow similar comparisons.

In the GYM, concerning RPE and [LA], they were measured only after the 3rd round and [LA] was measured after sparring only. Thus, only RPE exercise effects could be assessed and no difference was found between sparring and punching bag (12.9±1.8 &

12.6±1.9). In the LAB, RPE was similar for sparring and pad work (12.2±1.3 & 13.6±2.1), but [LA] was almost higher for sparring than for pad work (6.1±2.3 & 4.0±1.7 mmol· L^{-1}, respectively, $p<0.05$).

Most maximal values of the treadmill test (VO_2peak, HRmax and RPEmax) were higher ($p<0.05$) than values observed while doing sparring, pad work or punching bag in the GYM (no %VO_2peak values in that condition) or in the LAB (Figure 4). VO_2 values of LAB sparring, pad work and punching bag at 180 b·min^{-1} were similar (43.4±5.9, 41.1±5.1 and 38.3±6.5 ml·kg^{-1}·min^{-1}, respectively, $p>0.05$). However, VO_2 increased with the punching frequency (24.7±6.1, 30.4±5.8 and 38.3±6.5 at 60, 120 and 180 b·min^{-1}, respectively, $p<0.05$). Significant increases with punching frequency ($p<0.05$) were also observed for RPE and %HRmax (Figure 4). For %HRmax, sparring, pad work and punching bag at 180 b·min^{-1} in the LAB and punching bag in the GYM were all similar while sparring in the GYM was higher ($p<0.05$) and punching bag at 60 and 120 b·min^{-1}, was lower ($p<0.05$) (Figure 4). For RPE, only punching the bag at 60 b·min^{-1} was lower than other boxing exercises whether they were done in the LAB or in the GYM (Figure 4).

Our regression analyses indicated that the VO_2 cost of sparring (or its intensity) was not significantly ($p>0.05$) related to body weight ($r = 0.53$) nor to VO_2peak ($r = 0.51$). However the VO_2 cost of sparring tended to be inversely proportional to the body weight of boxers (Figure 5, upper graph), but proportional to their VO_2peak (Figure 5, lower graph), a trend that became significant when we duplicated the same results (same dispersion and twice the numbers of subjects).

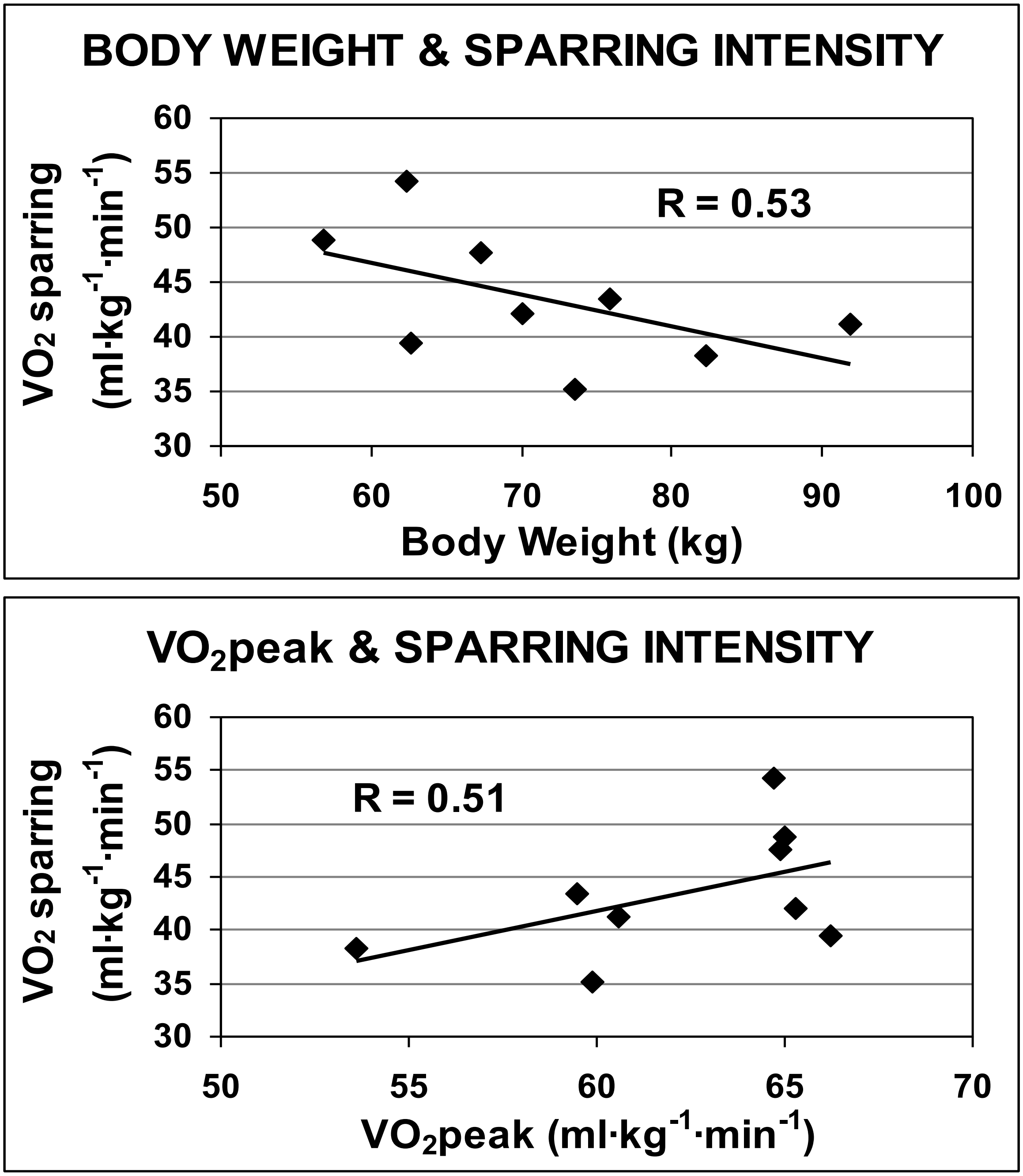

Figure 5. VO_2 cost of sparring tends to decrease (n. s. at $p>0.05$) as a function of body weight of boxers (upper graph) and tends to increases (n. s. at $p>0.05$) as a function of VO_2peak (lower graph).

5.0 DISCUSSION

Before discussing our results per se, it is worthwhile to discuss some methodological aspects of this study. The main purpose of this study was to quantify VO_2 requirements of various boxing exercises such as sparring, pad work and punching bag. Since VO_2 could not be measured in the natural GYM environment, we simulated boxing exercises in the LAB and developed a method to measure VO_2 for those boxing exercises by connecting subjects to the metabolic system immediately after three 2-min rounds of sparring and pad work while asking them to maintain the same level of exertion. However for the punching bag, subjects were connected to the metabolic system during the entire exercise. As indicated previously (Annex 1), this method was proven valid without systematic error when normalised and controlled exercises were performed on the treadmill. Since the subjects subjectively attempted to continue exercising at the same level of exertion, it is possible that exercise intensity may have been slightly lower or even higher. That is one limitation of our study but we do not expect a large error from that point of view.

From another point of view we can ask ourselves if simulated boxing exercises in the LAB realistically corresponds to natural GYM boxing exercises. Based on the higher sparring values of HR and [LA] observed in the GYM as compared to the LAB (Table 2), we may expect a slight underestimation of VO_2 values observed for sparring in the LAB. The fact that lower HR were observed in the LAB for punching the bag at 60 and 120 $b \cdot min^{-1}$ (67.5±3.5 and 74.8±5.9 %HRmax, respectively, Figure 4) compared to free punching bag in the GYM at a frequency of 70.6±22.6 $b \cdot min^{-1}$ (86.9±5.7 %HRmax, Figure 4 and Table 2), also indicates that power of the punches and/or the foot work rather than the punching frequency may explain the higher intensity of the GYM boxing exercises compared to the LAB exercises. Similar conclusion could be reached from RPE measures. Since we do not have any LAB-GYM comparison data for the pad work exercise, it is difficult to say if the observed energy cost is also underestimated for this activity, but there is no reason to believe so.

We did our measurements using 2-min rounds of boxing exercises, but actual ruling sets the round duration to 3-min for “elite amateur” and “professional” male boxers. The 2-min round rule is still valid for other boxers. In any event and at the same pace of exercise, the energy cost should not be affected by the length of the round since metabolic steady state is reached in about 2 min (4) as seen by continuous VO_2 recording. On the other hand, it is not excluded that boxers could decrease their metabolic rate due to fatigue, but this would need additional study to demonstrate it. From another perspective, our measurements only reflect the energy cost at the end of the last or third 2-min round. In other words, the exercises may not be steady state tasks and the values observed may not represent the average cost for those exercises, but some kind of a peak or an end value of the third round of exercise assuming that VO_2 increases from round to round and from 1st to 2nd min of each round.

Now that we better understand the methodological limitations, it seems easier to discuss the energy cost of boxing exercises. From our LAB measures, we can say that at least 43.4±5.9, 41.1±5.1 $ml \cdot kg^{-1} \cdot min^{-1}$ are required for sparring and pad work, respectively (Figure 4). These values correspond to 69.7±8.0 and 66.1±8.0 % of treadmill VO_2peak. Three months separated the VO_2peak test from VO_2 measurements during the boxing exercises. A possibility exists that these values changed during that time lapse. However for already well trained subjects like our boxers (62.2±4.1 $ml \cdot kg^{-1} \cdot min^{-1}$), VO_2peak improvement is usually less than 2 $ml \cdot kg^{-1} \cdot min^{-1}$ over a 3-months period even with very intense training (4). In summary, with VO_2 requirements just over 40 $ml \cdot kg^{-1} \cdot min^{-1}$, boxing may not be a typical aerobic sport such as middle or long distance running with known VO_2max values in the 70.0 to 85.0 $ml \cdot kg^{-1} \cdot min^{-1}$ range, but a minimal of aerobic fitness may help to maintain 1st round pace till the end of the fight.

Our sparring average VO_2 value is higher (see introduction) than the ones reported by Seliger (24,25), Durnin (11), Ainsworth et al. (2,3) and Ostyn et al. (21) possibly due to the limitations of their methodological equipment (24,25) or computation (2,3,11,21). However, using treadmill HR/VO_2 regression, Chatterjee et al. (7,8,9) reported similar VO_2 values for women sparring with an increase of 40.3±7.0 to 46.6±6.6 $ml \cdot kg^{-1} \cdot min^{-1}$ from round 1 to round 3. That is also expected from the increased %HRmax observed from round 1 to round 3 by our own subjects while sparring in the GYM. It is difficult to say which values represent the true values. Morita et al. (18) found that treadmill HR/VO_2 regression yielded biased VO_2 estimates as compared to boxing HR/VO_2 regression or simply VO_2 measured during shadow, pad work, heavy bag and punching ball exercises. The lower values reported by Seliger (24,25) may be due to hindered movement while carrying meteorological balloons during sparring and punching bag. Furthermore, with a collecting gas valve in the face, it is difficult to study “true” sparring as we did in our study. The studies that involved “true” sparring, were estimating VO_2 from HR/VO_2

regression, a procedure that is not very accurate particularly if the regression was obtained on the treadmill (18). On the other hand, measurements of HR and [LA] were easily obtained during "true" sparring and values of ~180 $b \cdot min^{-1}$ (7,8,9,12,18) and 9-10 $mmol \cdot L^{-1}$ (8,12) were reported, which is similar to our "true" sparring HR and [LA] values and thus confirms the intensity of sparring in the GYM. However, lower HR values of ~170 $b \cdot min^{-1}$ were reported by Seliger (24,25), but their boxers wore a mouth piece connected with tubing to meteorological balloons on their back. Thus we feel that our values represent a good estimate of the average cost of "true" sparring and pad work. In any event, the average values may not be representative for all boxers. With an average around 40 $ml \cdot kg^{-1} \cdot min^{-1}$ and a standard deviation around 5 $ml \cdot kg^{-1} \cdot min^{-1}$ for sparring and pad work, it means that based on a normal distribution, around 32 % of boxers are either below 35 or above 45 $ml \cdot kg^{-1} \cdot min^{-1}$ when doing those activities. Thus, it is important to exercise caution before generalising average values to all individuals. Some of these differences may be due to the weight or the fitness level of the boxers. Typically, compared to light boxers, heavy ones tend to move slowly in the ring. In our study, there was a tendency for a lower VO_2 cost in heavier boxers (Figure 5), a tendency that might be significant with a larger number of subjects. Similarly the boxers with better VO_2peak tend to have higher VO_2 cost of sparring or to invest themselves more during sparring (Figure 5). Although logical and interesting, that needs to be confirmed with a larger sample.

Now let us discuss the energy cost of punching the bag. Our LAB measurements at frequencies of 60, 120 and 180 $b \cdot min^{-1}$, yielded VO_2 costs of 24.7±6.1, 30.4±5.8 and 38.3±6.5 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. For free punching bag in the GYM at 70.6±22.6 $b \cdot min^{-1}$, using LAB VO_2 data at 60 $b \cdot min^{-1}$ grossly underestimates the metabolic cost since the punching intensity was probably much larger. However, since %HRmax and RPE are similar to the ones observed during punching the bag at 180 $b \cdot min^{-1}$ in the LAB, the VO_2 cost of free punching bag exercise in the GYM is probably closer to the LAB cost at 180 $b \cdot min^{-1}$ (38.3±6.5 $ml \cdot kg^{-1} \cdot min^{-1}$, Figure 4). This value is a bit lower than the values we obtained for sparring and pad work which is consistent with the results of Seliger (24,25).

Thus in addition to foot work, higher power of the punches in the GYM may explain these higher RPE and HR values. In their study, Kravitz et al. (13) also measured the VO_2 cost of punching at different frequencies. Keeping in mind that they have used recreational fitness boxers hitting a SLAMMAN instead of a regular suspended punching bag, they have reported values around 27.0-30.0 $ml \cdot kg^{-1} \cdot min^{-1}$ for punching frequencies between 60 and 120 $b \cdot min^{-1}$. This is almost identical to our values but probably underestimates the real cost of punching in the GYM with elite boxers for the reasons mentioned above. Furthermore, O'Driscoll et al. (20) reported values of 31.5±6.9 $ml \cdot kg^{-1} \cdot min^{-1}$ for a punching frequency of 134 $b \cdot min^{-1}$ which is in between our values at 120 and 180 $b \cdot min^{-1}$ and Adams et al. (1) reported values of 22.9±10.0 $ml \cdot kg^{-1} \cdot min^{-1}$ which is lower than our values obtained for the same punching frequency of 120 $b \cdot min^{-1}$. However, other studies (2,3,19,24,25) reported values between 18.9 and 27.0 $ml \cdot kg^{-1} \cdot min^{-1}$ for free training of boxing on the punching bag which would be lower than our estimate of 38.3±6.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (see above).

These discrepancies in the punching bag cost may be due to different methodologies such as the VO_2 measures, the punching power or frequency and the integration or not of footwork... However, Morita et al. (18) reported values of 52.5±7.1 $ml \cdot kg^{-1} \cdot min^{-1}$, which this time is much larger than our 38.3±6.5 $ml \cdot kg^{-1} \cdot min^{-1}$ estimate for free punching on the bag. We do not have any explanation for that but it is interesting to note that their values were slightly higher than the VO_2max of their subjects. Thus, our 38.3±6.5 $ml \cdot kg^{-1} \cdot min^{-1}$ estimate for 3 rounds of free punching bag, corresponds to 61.7±10.3 %VO_2peak, and is a much lower value than ~100 %VO_2peak. On the other hand, it is quite feasible to reach VO_2max on the punching bag if a boxer punches as fast and as hard as possible and gets exhausted at the end of a single round of punching bag. Interestingly, one study reports that between 2 boxers with similar HR response, the one with the largest punching power has the lowest punching frequency (17). The energy cost of punching is thus related to many conditions and it is very difficult to attribute a single value for this particular exercise.

6.0 PRACTICAL APPLICATIONS

Even though boxing requires a combination of technical, tactical, mental and physical skills, this study indicates that aerobic fitness is certainly one of the important physical qualities to consider as seen by a VO_2peak of 62.2±4.1 $ml \cdot kg^{-1} \cdot min^{-1}$ and a relative intensity of ~70 $\%VO_2peak$ for the most demanding boxing exercises such as sparring and pad work. This also gives an indication for the minimal level of aerobic training stimuli required for the boxers since the intensity could be higher in real competition. However, aerobic fitness is probably more important as the duration or the number of rounds increases. From another point of view, punching frequencies of around 35 and 60 $b \cdot min^{-1}$ in sparring and pad work, respectively, were observed in this study and gives an idea of the frequency that should be used when training those abilities. To be more specific, our study is the only one to measure the VO_2 cost of “true” sparring and those values indicate 1) the importance of VO_2max in the training program of the boxer 2) and the minimal intensity at which training loads should be set for aerobic training. This study also reports punching frequency data for sparring, pad work and free training on the punching bag that could be used as training guides for boxers.

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ANNEX 1 TO EXPERIMENTAL STUDY

Validation of post-exercise measurements to estimate exercise VO_2

9.0 INTRODUCTION

In some exercises such as sparring, while the boxer may receive punches to the head and upper body, it is not possible to wear a collecting gas valve in the face or a portable VO_2 system on the chest to collect expired gasses. VO_2 could be estimated from individual HR/VO_2 regression, but those estimations are not accurate, particularly if the regression is obtained from another type of exercise (e.g. Treadmill vs. Sparring) (4). Since none of these two traditional methods permit proper measurements of true sparring VO_2, we developed a new method to do so, i.e. a method that measures VO_2 of true sparring with actual punches to the face and chest. With this method, the subjects are connected to the metabolic system right at the end of an exercise bout done at a relatively constant intensity that lasts at least 2 min in order to reach steady VO_2 (e.g. third 2-min round of sparring) and are instructed to keep moving their legs and arms to maintain their metabolic activity at the same level as it was before the connection. When the metabolic system reaches equilibrium (≥30 s to wash the system), VO_2 is recorded as the exercise steady state or average value. The general purpose of this study was to validate this approach to measure VO_2 in field conditions.

10.0 METHODS

10.1 Subjects

Nine kinesiology students (age = 27.0±13.4 yr, height = 174.0±7.9 cm and weight = 76.2±16.8 kg), volunteered to participate to this validation process.

10.2 Factors to Consider

When the method is used in the field, gases are collected only at the end of a task done at a relatively constant intensity, for example, after the third 2-min round of sparring. In order to validate these measures, a criterion measure was required which was VO_2 during the exercise itself. Thus, in the validation process VO_2 was measured both during the exercise and after the exercise. Furthermore, for the post-exercise measures in field conditions, we asked the subjects to continue to move at the same intensity immediately after being connected to the metabolic system to avoid the recovery process. In the validation study, treadmill exercise was used in order to be able to measure VO_2 both during the exercise itself and after the exercise.

One more aspect needs to be considered. When used in field conditions, the metabolic system may often be disconnected from the subjects for 10-16 min periods before reconnecting the subjects for the post-exercise measurements. Therefore, during the validation process, the exercise steady state criterion measures were taken ~15-30 min before the post-exercise measures. This happened many times after the initial calibration in order to validate the method at different intensities. We thus developed an exercise pattern that takes into consideration all these aspects including the calibration that was made up to 85 min before numerous connections and disconnections to the metabolic system.

The validation study was thus designed to answer the following questions:

1) How are VO_2 values affected by many 10-16 min disconnections from the metabolic system after initial calibration?
2) Can the gas analysing system stay calibrated for up to 85 min?
3) How long does it take to wash the metabolic system from zero input and to reach VO_2 equilibrium?
4) Are three 2-min rounds of running exercise with 1-min rest in between enough for the subjects to reach a steady state VO_2?
5) How does exercise intensity affect the accuracy of the post-exercise measures?
6) Are the post-exercise values significantly different from the criterion values?

10.3 Validation Protocol

Each subject ran on the treadmill at 3 different intensities for at least 2 min continuously in order to reach metabolic steady state. Intensities were chosen in order to cover subjects capacity and a wide range of energy costs. Each intensity was done twice: 1st time to obtain criterion VO_2 values and 2nd time to see if the post-exercise VO_2 values were the same as the criterion values. For the post-exercise measures of the validation process, the subjects briefly stopped running to connect themselves to the gas analysing system and hopped back on the treadmill to continue running at the same speed to avoid recovery process for the collection periods. To summarize, the subjects 1) ran on the treadmill while their criterion exercise VO_2 were measured, 2) took a 8-10 min rest, 3) got back on the treadmill for 4-8 min without being connected to the system to mimic various field conditions, 4) stopped running for 10-15 s to put a nose clip and to connect themselves to the metabolic system and 5) got back on the treadmill for 1.75-2 min to collect the post-exercise measures. The protocol is illustrated in Figure 1. The black line is the predicted VO_2 costs of treadmill running using Léger's equation (2,3):

VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) = 2.209 + 3.163 speed ($km \cdot h^{-1}$) (Equation 1)

The predicted cost is thus proportional to the speed pattern of the protocol and illustrates the actual exercise workload and also enables a comparison of the VO_2 values obtained with our system and the values reported in the literature. Each subject had a different set of speeds. The individual kinetic of VO_2 measured during and after exercise at 3 different speeds for one subject is also illustrated in figure 1 (gray line) and enables comparison between exercise and post-exercise measures and between literature predicted costs for 3 different intensities. Similar curves were obtained for all the subjects.

10.4 Statistical Analyses

"Post-exercise VO_2 measures", "criterion exercise VO_2 measures" and "literature predicted VO_2 values" (Equation 1) were compared for each running intensity using a 2-way ANOVA for repeated measures and Tukey a posteriori tests. A linear regression and a scatterplot were also done to compare "post-exercise VO_2 measures" and "criterion exercise VO_2 measures". Unless otherwise stated, all reported differences are significant at the $p \leq 0.05$ level.

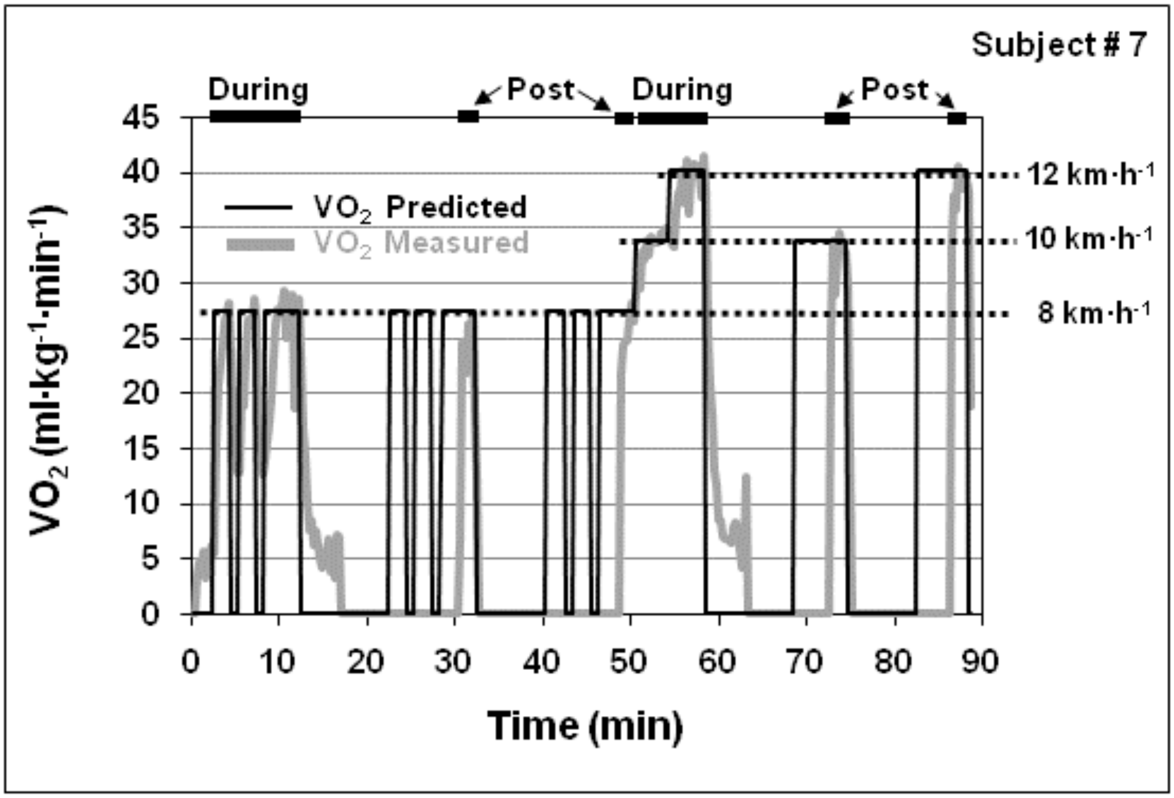

Figure 1. Typical individual kinetic of predicted and measured VO_2 during and after exercise at 3 different intensities.

11.0 RESULTS

Figure 1 is a typical representation of VO_2 predictions and VO_2 measurements during and after exercise at 3 different intensities during the exercise protocol for one subject. Similar patterns were obtained for all the subjects. Figure 2 summarizes the results of the whole group and illustrates similar values between criterion exercise, post-exercise and literature predicted VO_2 values. This is observed for the whole range of investigated metabolic levels. Not only the values obtained immediately after reconnecting the subjects to the metabolic system were similar to the criterion exercise values, but these two values were also similar to reported values in the literature indicating no important systematic differences between these VO_2 values. Furthermore random variation between VO_2 measured during running or immediately after reconnecting the subjects to the metabolic system were very small as seen by the high correlation and the small standard error of the estimate ($r = 0.96$, SEE = 1.6 $ml \cdot kg^{-1} \cdot min^{-1}$, Figure 3) between these 2 variables.

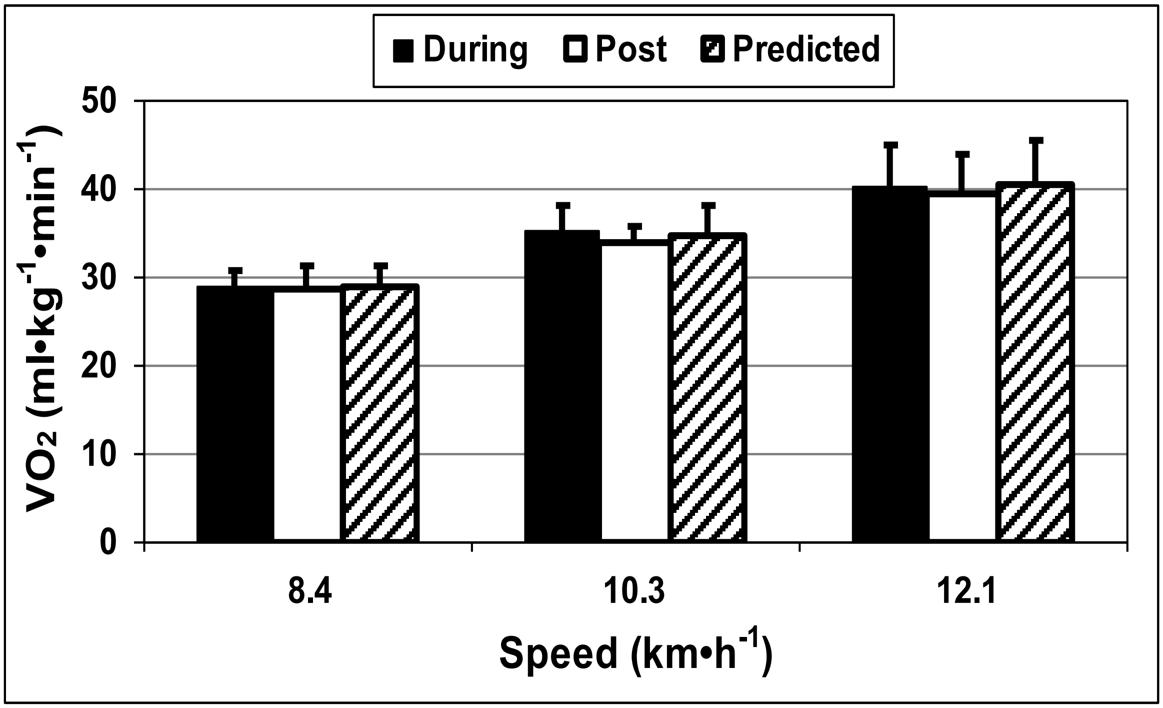

Figure 2. Comparison between predicted VO_2 (Equation 1) and VO_2 measured during and after exercise for 9 subjects at 3 intensities (Differences between type of VO_2 estimates: n.s., $p>0.05$; intensity effect: $p<0.05$).

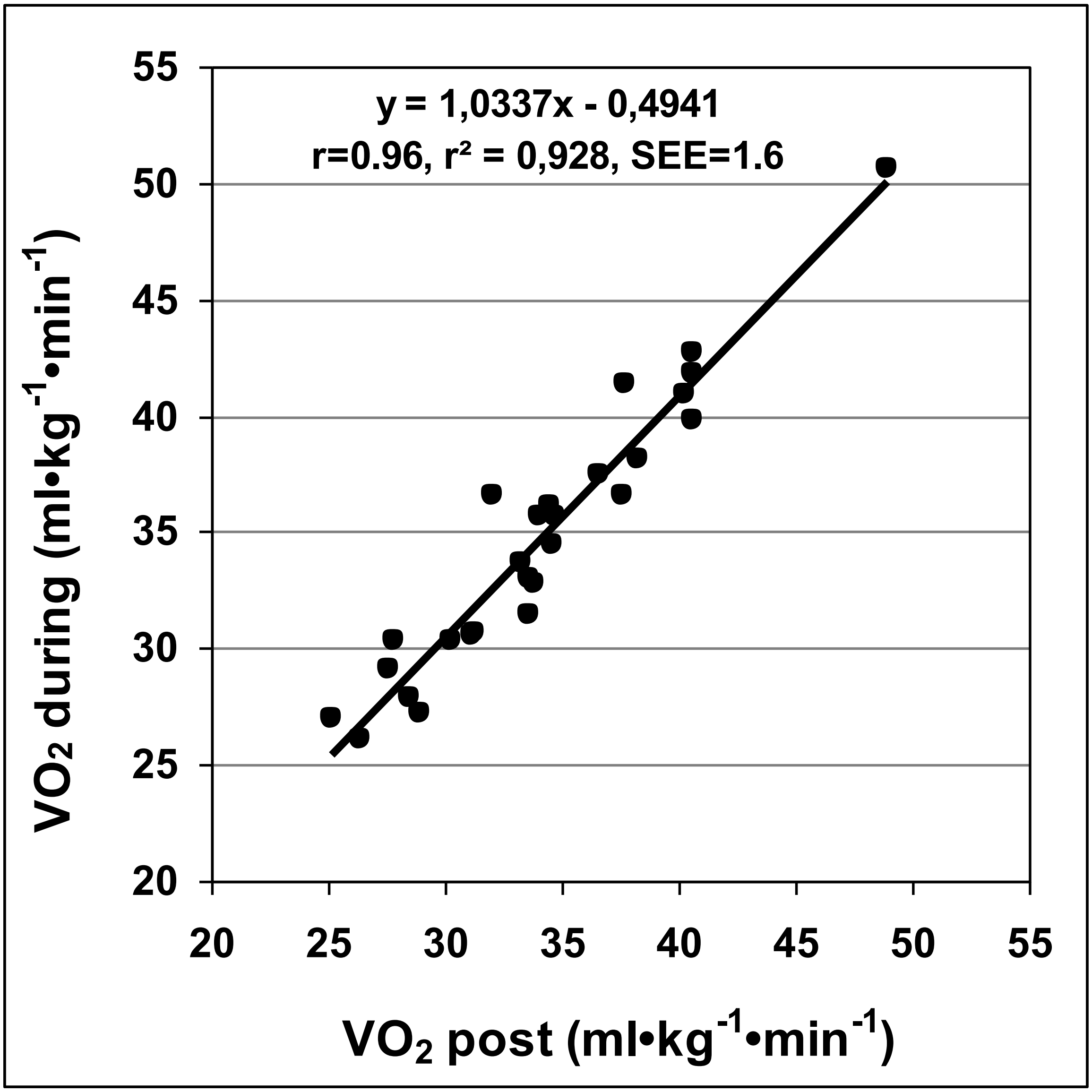

Figure 3. Regression and Pearson correlation between VO_2 measured during and after exercise for 9 subjects at 3 intensities.

A closer look at the individual curves with extended abscissas (Figure 4) illustrates that the system equilibrium is reached between 30 and 75 s (2^{nd} to 5^{th} 15-s sample) after reconnection. Similar results were systematically obtained for all the subjects, indicating that only a short delay or a short time-sampling collection is required to obtain proper VO_2 values after reconnecting the subject.

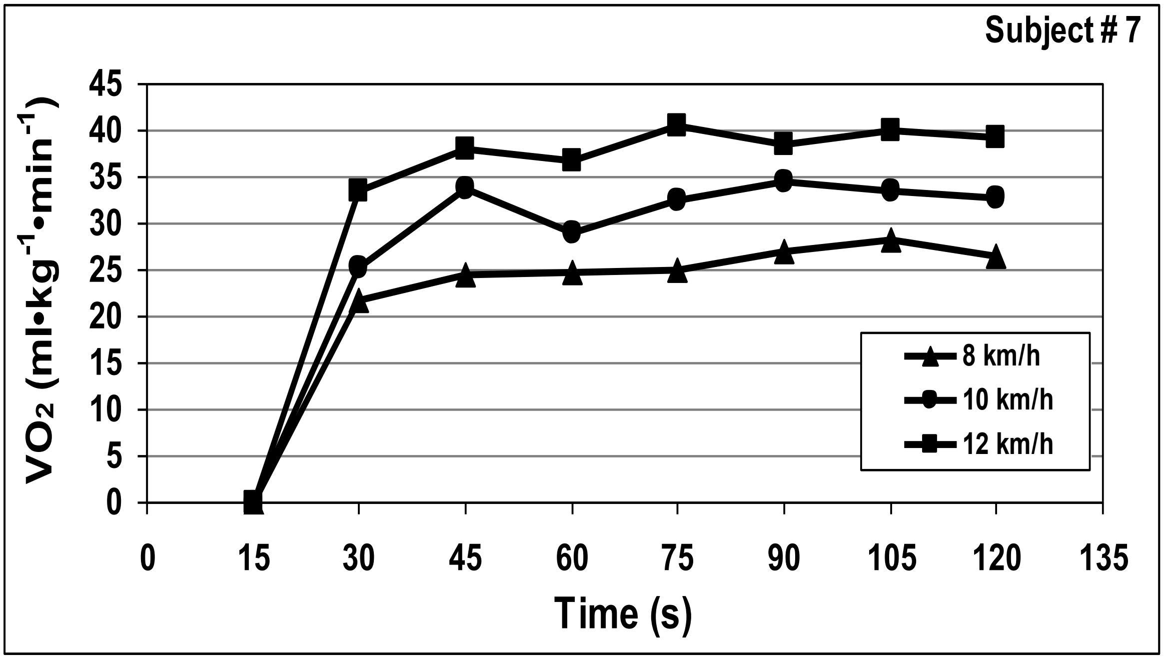

Figure 4. Typical enlarged individual and superposed VO_2 kinetic after reconnecting the subject to the metabolic system at 3 different intensities. The system reaches equilibrium from the 2^{nd} 15-s sample or 30 s after reconnecting the subjects.

12.0 DISCUSSION

Our metabolic system yields similar exercise and post-exercise VO_2 values for the same workload after being disconnected many times for 10-16 min periods. Thus it is not a problem to measure VO_2 many times after different tasks of various intensities between 8 to 13 $km \cdot h^{-1}$ or ~25 to 45 $ml \cdot kg^{-1} \cdot min^{-1}$ while the metabolic system is disconnected in between and calibrated up to 85 min before. Furthermore, we can see that the metabolic system adjusts itself within 30-45 s after reconnecting the subjects. Finally, we can see that three 2-min periods of exercise are enough to achieve metabolic steady state and that attained VO_2 values truly reflect the energy cost of the activity being measured which is in conformity with the classical work of Astrand (1). Of course we used well controlled treadmill running instead of subjective arm and leg exercise during the post-exercise period of the validation process. Although we cannot be totally sure, the error should not be much different when the level of activity is subjectively maintained after reconnecting the subject to the metabolic system when the method is used with other types of activities where it is not possible to wear a respiratory face mask (e.g. sparring). Therefore, it is difficult to say if the limitations of the present approach are smaller or larger than the limitations of approaches used in previous sparring studies. However, the results we obtained with this new approach certainly bring new insight in the VO_2cost of true sparring. Thus, the results of this validation process confirm the potential of this new approach in field conditions for our metabolic system at least.

These results were obtained with the same metabolic system used with the boxers in the experimental study. With other models or brands of metabolic system however, we recommend to check as we did the stability of the VO_2 measures for many disconnections and connections after the initial calibration and to check the time required by the metabolic system to reach equilibrium values after reconnecting the subjects from a zero input signal. Furthermore, before measuring the energy cost of a new activity with this approach, it is also recommended to check if the metabolic system used yields treadmill or cycling VO_2 values that are similar to accepted literature values.

13.0 CONCLUSION AND PRACTICAL APPLICATIONS

That method was developed to determine the VO_2 cost of relatively steady state 2-min rounds of sparring and pad work in boxing but could also be useful in other field situations 1) where the use of a portable VO_2 system seriously hinders the motion pattern or 2) where such a portable system is not available. It is however important to make sure that the subjects are relatively in a steady state before connecting the subjects to the metabolic system and that the subjects continue to exercise at the same level during the measurement phase.

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