©Journal of Sports Science and Medicine (2006) **CSSI,** 74-89
http://www.jssm.org

Combat Sports Special Issue

Research article

PHYSIOLOGICAL PROFILE OF SENIOR AND JUNIOR ENGLAND INTERNATIONAL AMATEUR BOXERS

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Published (online): 01 July 2006

ABSTRACT
Despite worldwide popularity of amateur boxing, research focussed on the physiological demands of the sport is limited. The physiological profile of Senior and Junior England international amateur boxers is presented. A gradual (8 to 21-days) and rapid (0 to 7-days) phase of body weight reduction was evident with 2.2 ± 0.3 % of the 7.0 ± 0.8 % weight loss occurring over the final 24-hours. An increase in body weight >4% was observed following a recovery period. High urine osmolality values (> 1000 $mOsm \cdot kg^{-1}$) were recorded during training and competition. High post-competition blood lactate values (>13.5 $mmol \cdot l^{-1}$) highlighted the need for a well-developed anaerobic capacity and the importance of not entering the ring in a glycogen depleted state. The aerobic challenge of competition was demonstrated by maximum heart rate values being recorded during ‘Open’ sparring. Mean body fat values of 9-10% were similar to those reported for other weight classified athletes. Normal resting values were reported for hematocrit (*Senior* 48 ± 2 % and *Junior* 45 ± 2 %), haemoglobin (*Senior* 14.7 ± 1.0 $g \cdot dl^{-1}$ and *Junior* 14.5 ± 0.8 $g \cdot dl^{-1}$), bilirubin (*Senior* 15.3 ± 6.2 $\mu mol \cdot l^{-1}$) and ferritin (*Senior* 63.3 ± 45.7 $ng \cdot ml^{-1}$). No symptoms associated with asthma or exercise-induced asthma was evident. A well-developed aerobic capacity was reflected in the Senior VO_{2max} value of 63.8 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$. Senior lead hand straight punching force (*head* 1722 ± 700 N and *body* 1682 ± 636 N) was lower than the straight rear hand (*head* 2643 ± 1273 N and *body* 2646 ± 1083 N), lead hook (*head* 2412 ± 813 N and *body* 2414 ± 718 N) and rear hook (*head* 2588 ± 1040 N and *body* 2555 ± 926 N). It was concluded that amateur boxing performance is dependent on the interplay between anaerobic and aerobic energy systems. Current weight making methods may lead to impaired substrate availability, leading to reduced competitive performance and an increased risk to a boxers health.

KEY WORDS: Urine osmolality, blood lactate, VO_{2max}, punching force.

INTRODUCTION

Historical overview

Fundamental changes to the rules and regulations governing the sport of boxing have taken place over the past 5000 years. Specifically, the development of equipment (i.e., gloves and headguard), contest format (i.e., number and duration of rounds) and the introduction of a weight classification system (i.e., 48-91+ kg). However, despite these changes a number of similarities still exist. For example, significant differences in body weight between boxers immediately prior to competing is evident, despite the introduction of weight categories (Smith, 1998). A historical review of the sport provides an insight into the cultural, political and philosophical perspectives that provided the stimulus for change. The origins of pugilism can be traced back over

5000 years to the King's Festivities in Ancient Egypt. Illustrations indicate that pugilists fought naked before the Gods with a technique dependent upon one arm protecting the head and the other being used in attack (Prior, 1995). Paintings of boys fighting in Crete during 2000 BC reveal that helmets, the first type of head guard, were worn to protect the head and face from punishment and a glove to protect the attacking hand. Vase paintings from Cyprus in 1200 BC suggest the intention of the attacking fighter was to throw punches to the head rather than the body (Ellwanger, 1996). At the Olympic Games of 776 BC competitors fought in a sport known as 'pankration' that combined the techniques of wrestling and boxing (Hickey, 1980). There were no weight categories and fighters competed wearing a belt and a type of leather glove called a 'cestus'. The fight was not divided into rounds, with the winner being decided when one of the competitors admitted defeat. The first Olympic pugilism took place at the Olympiad of 688 BC. Pugilists wore a 3-metre narrow thong of leather around each hand and forearm, soaked in fat, which enabled them to make a fist. There were normally 5 to 12 pugilists in 3 or 4 eliminatory rounds. There existed no weight classifications and clinching was forbidden (Kluge, 1996). In Greece, at around 400 BC attitudes towards pugilism were changing. Society began to demand that athletes become more competitive and contact sports, such as pugilism had a more violent nature. At this time the basic 'stance' and 'on-guard' position of the pugilist was developed (Prior, 1995). In 393 AD Emperor Theodosius I banned the Olympic Games, with the number of pugilists declining until they eventually disappeared during the fourth century AD (Ellwanger, 1996). It is generally agreed that the Ancient form of pugilism re-emerged during the 17th Century as prize-fighting. Events such as the 1634 Cotswold Games included prize-fighting where spectators bet heavily upon the outcome of the fight. Prize-fighters were recruited from the working classes under the patronage of the middle and upper classes (Hickey, 1980). As prize-fighting grew in popularity boxing 'schools' and 'academies' were set up by prize-fighters to offer the middle and upper classes the opportunity to learn the skills and techniques underpinning the 'Noble Art' (Prior, 1995). It could be argued that these individuals were the first recognised boxing coaches. The first set of boxing rules were introduced by Jack Broughton (1742) yet they did little to prevent the number of serious injuries and deaths resulting from prize-fighting. In 1867 John Sholto Douglas (9th Marquis of Quennsbury), along with close friend John Graham Chambers, constructed a new set of rules to check the excesses of prize-fighting. One of the major rule changes was that fighters wore gloves and there was an attempt to match fighters according to body weight (Prior, 1995).

Development of a weight classification system

During the late 1600's to mid 1800's prize-fighting took place between fighters not matched by body weight. In 1841 William 'Tipton Slasher' Perry fought Charles Freeman whilst weighing 38.2 kg lighter than his opponent (Brailsford, 1988). The first regulated weight classification system in boxing was introduced in 1867 and was based upon the principle of making competition fairer by minimising differences in body weight between competitors. During the period 1867-2002 the number of weight categories in Senior international amateur boxing increased from 3 to 12, ranging from light-flyweight (48 kg) to super-heavyweight (91+ kg). However, in 2003 the 63.5 kg, 67 kg, and 71 kg divisions were replaced by a 64 kg and 69 kg category, resulting in the current 11 international Senior competition weight classes.

Contest format

The duration of a boxing contest has undergone radical change since the Cotswold Games in 1634. Without regulation the length of many prize-fights lasted several hours with a time of 3-hours 15-minutes being recorded for the fight between Simon Byrne and James 'Deaf' Burke in 1833 (Miles, 1880). In 1880 the Amateur Boxing Association of England was formed and stipulated that the length of a contest would be restricted to 3 rounds. Rounds 1 and 2 were of 3-minutes duration with round 3 lasting for 4-minutes. The recovery period between rounds was set at 1-minute. However, if the score of the contest was level after 3 rounds a fourth round of 2-minutes was allowed in order to determine a winner (Hickey, 1980; Prior, 1995). From an energy provision perspective this change in contest format increased the importance of energy supply from anaerobic sources. In 1926 the contest format was changed so that all contest took place over 3 rounds of 3-minutes duration with a 1-minute interval between rounds. In 1997 the world governing body (Association Internationale de Boxe Amateur, AIBA) increased the number of rounds to 5 and decreased the duration of each round to 2-minutes. This change was not viewed positively. Under pressure from boxers, coaches and officials, the number of rounds was reduced by AIBA to 4 prior to the 2000 Olympic Games.

Method of scoring

Boxing has always been scored using subjective marking. At the 1908 Olympic Games two judges and a referee awarded up to 5 points per round for

Table 1. Magnitude (kg), percentage of body mass (%) and time-scale of body weight reduction in Senior England international amateur boxers (n = 82) from 13 weight categories. Data are means (±SD).

Weight category (kg)	Number of boxers	Days prior to Official weigh-in 21	7	3	1
48	6	3.1 (.7) (6.5%)	2.4 (1.0) (5.0%)	1.5 (.7) (3.1%)	.9 (.5) (1.9%)
51	5	3.8 (.9) (7.5%)	2.8 (.5) (5.5%)	2.2 (.2) (4.3%)	1.2 (.2) (2.4%)
54	8	3.6 (.8) (6.7%)	2.6 (.8) (5.1%)	1.5 (.6) (2.9%)	.9 (.3) (1.7%)
57	7	3.4 (.5) (6.0%)	2.5 (.5) (4.4%)	1.9 (.5) (3.3%)	1.0 (.3) (1.8%)
60	5	3.8 (1.1) (6.3%)	2.8 (.9) (4.7%)	2.0 (.7) (3.4%)	1.2 (.7) (2.0%)
*63.5	9	4.8 (.6) (7.6%)	3.6 (.6) (5.7%)	2.6 (.6) (4.1%)	1.4 (.3) (2.2%)
♦64	4	4.0 (.6) (6.3%)	3.3 (.6) (5.2%)	2.4 (.4) (3.8%)	1.4 (.4) (2.2%)
*67	6	4.5 (.7) (6.7%)	3.7 (.7) (5.5%)	2.6 (.5) (3.9%)	1.8 (.5) (2.7%)
♦69	5	4.3 (.7) (6.2%)	3.4 (.5) (4.9%)	2.4 (.7) (3.5%)	1.6 (.5) (2.3%)
*71	7	4.4 (.5) (6.2%)	3.6 (.5) (5.1%)	2.7 (.3) (3.8%)	1.7 (.5) (2.4%)
75	9	6.2 (1.5) (8.3%)	4.1 (.9) (5.5%)	3.1 (.6) (4.1%)	1.8 (.3) (2.4%)
81	5	6.6 (.9) (8.1%)	4.2 (.7) (5.2%)	2.9 (.2) (3.6%)	1.9 (.2) (2.4%)
91	6	7.4 (1.2) (8.1%)	4.7 (1.2) (5.2%)	3.2 (1.0) (3.5%)	1.9 (.7) (2.1%)
	average	7.0 (±.8%)	5.2 (±.4%)	3.6 (±.4%)	2.2 (±.3%)

[NB: (a) In 2003 rule changes to the weight classification system for Senior amateur boxers resulted in the 63.5 kg, 67 kg and 71 kg categories (*) being replaced by a 64 kg and 69 kg category (♦). (b) Super-heavyweight (91+ kg category) not included as weight manipulation not practised].

the first 2 rounds and up to 7 points for the last round (Prior, 1995). It was not until the 1932 Olympic Games that the referee actually joined the boxers inside the ropes (Kluge, 1996). Following biased judging at the 1988 Olympic Games AIBA introduced a computer method of scoring. Five neutral judges were required to press a red or blue button (corresponding to the boxer competing out of the red or blue corner) when they believed a boxer had landed a punch with sufficient force on their opponents target area. For a punch to be registered as a scoring blow three or more of the judges had to press the same coloured button within 1-second. The change to computer scoring radically changed training methods with greater emphasis placed on developing punching force and less time devoted to developing flair (Smith, 1998).

The global appeal of amateur boxing is reflected in 196 nations affiliated to AIBA in 2005 (AIBA, 2005). However, given its worldwide popularity and high levels of participation previous research related to amateur boxing is scarce. Given the physiological demands that appear to accompany a competitive bout and the added complication of it being a weight classified sport, this omission is somewhat surprising. The purpose of this study is to examine the physiological demands of amateur boxing and provide a physiological profile of the elite amateur boxer.

METHODS, RESULTS AND DISCUSSION

Data acquisition

Information presented in the following sections was recorded between 1987 and 2004. The data sets have been selected to highlight specific issues and specifically focus on Senior England international amateur boxers (18 to 34-years, n = 130). Where appropriate, data sets relating to Junior England

Table 2. Type and popularity (%) of weight loss methods practised by Senior England international amateur boxers over a 21-day weight-making period (n = 82).

	Method	Days prior to Official weigh-in			
		21	**7**	**3**	**1**
Passive	Fluid restriction	7/82 (8.5%)	55/82 (67%)	75/82 (92%)	78/82 (95%)
	Energy restriction	19/82 (23%)	72/82 (88%)	79/82 (96%)	82/82 (100%)
	Sauna	0/82 (0%)	11/82 (13%)	15/82 (18%)	17/82 (21%)
Active	Running	66/82 (80%)	75/82 (91%)	77/82* (94%)	66/82* (80%)
	Gym work	82/82 (100%)	82/82 (100%)	82/82* (100%)	55/82* (67%)

[NB: * Denotes boxer wearing extra layers of clothing or plastic wet suits to facilitate rapid fluid loss via sweating].

international boxers (16 to17-years, n = 26) are presented. Section 1 examines the physiological demands of amateur boxing from data recorded during training and competition. Section 2 presents normative physiological data from laboratory-based assessments. All data are expressed as group mean and standard deviation unless specified otherwise. Although not scientifically correct the term body weight is used in preference to body mass throughout this review as this reflects current terminology used when discussing weight-classified sports.

SECTION 1

Body weight manipulation.

Senior England international amateur boxers have been reported to reduce body weight prior to competing in an attempt to gain a physiological and psychological advantage over competitors in the same weight category (Hall and Lane, 2001, Smith, 1993; Smith et al., 2001). Data contained in Table 1 supports this statement with boxers from all weight categories (excluding super - heavyweight) experiencing a 6.0 to 8.3 % (7.0 ± 0.8 %) decrease in body weight over a 21-day pre-contest pre-contest period. A consistent pattern of weight loss was observed for all weight categories, comprising of a gradual and rapid phase. A 1.7 ± 0.7 % decrease in body weight occurred during the 8 to 21-day pre contest gradual phase. During the rapid phase a 5.2 ± 0.4 % reduction in body weight was observed over the final 7-days prior to competing. Of particular interest was the need for boxers from all categories to reduce body weight between 1.7 to 2.7 % over the final 24-hours. The reliance of boxers to make weight by rapid reductions in body fluid is evident. The existence of a gradual and rapid phase of weight reduction within a weight category sport supports the findings of Fogelholm (1994). The magnitude and time-scale of weight manipulation is similar to previous research related to wrestlers (Tipton and Tcheng, 1970; Steen and Brownell, 1990), judo players (Umeda et al., 2004), national hunt jockeys (Cotterill, 1992), lightweight rowers (Koutedakis et al., 1994), and lightweight American football players (Depalma et al., 1993).

Methods of weight loss

It is evident from Table 2 that Senior England international amateur boxers combine both passive and active methods of weight loss when making the competition weight. Similar findings have been reported extensively in high school and college wrestling (Herbert and Ribisl, 1972; Zambraski et al., 1976; Steen and McKinney, 1986 and Horswill, 1992). A decrease in body weight recorded during the 8 to 21-day gradual phase was achieved by an increase in energy expenditure leading to a period of negative energy balance. This was primarily achieved by increasing the amount of time spent undertaking active methods of weight loss (gym work 100 % and running 100 %) and supported by passive methods (energy restriction 23 %). Koutedakis et al. (1994) reported a 6 % reduction in body mass over a 2-month period for elite female lightweight rowers following modifications to training and energy intake. In a case study,, Widerman and Hager (1982) reported that modifications to a wrestlers training and diet over a 53-day period resulted in the loss of 12.7 % body weight.

During the 7-day rapid phase immediately prior to competition a greater interplay between active and passive methods is evident, with the role of passive methods becoming increasingly important. A comparison of the 3-day versus 1-day data indicates that boxers decreased the time spent undertaking active methods (running decreased from 94 % day-3 to 80 % day-1 and gym work from 100 % day-3 to 67 % day-1) and increased opportunities to adopt passive techniques (energy restriction increased from 96 % day-3 to 100 % day-1 and fluid restriction from 92 % day-3 to 95 % day-1). Steen and Brownell (1990) reported similar findings amongst College wrestlers with 94 % and 95 % practising some degree of energy and fluid restriction, respectively. The key role fluid manipulation plays within the weight making process is highlighted in the sauna data whereby 13,

Table 3. Fluid and energy intake of Senior England international amateur boxers over a 24-hour period immediately pre and post weigh-in.

Weight division (kg)	**24 hour Pre weigh-in**		**24 hour Post weigh-in**	
	Fluid intake (l)	**Energy intake (kcal)**	**Fluid intake (l)**	**Energy intake (kcal)**
60	0.6	569	1.5	2371
67	0.9	208	3.0	4589
71	1.4	295	5.5	4792
75	1.6	1338	3.0	5760
81	1.2	2605	4.2	5266
91	1.5	1292	2.0	3689
Means (SD)	*1.2 (.5)*	*1051 (901)*	*3.2 (1.5)*	*4411 (1217)*

18 and 21 % of boxers employed this technique 7-days, 3-days and 1-day prior to the weigh-in, respectively. However, the use of sauna by boxers reported in Table 2 is lower than those reported for wrestlers (Steen and McKinney, 1986; Steen and Brownell, 1990) and national hunt jockeys (Cotterill, 1992; Northcott, 1998). The importance of rapid fluid loss is further highlighted by the decision made by a significant number of boxers to wear extra layers of clothes or plastic wet suits whilst engaged in active methods of weight loss during the final 3-days prior to the official weigh-in. The use of clothing induced thermal dehydration, combined with exercise, has been well documented in high school and college wrestlers (Tipton and Tcheng, 1970; Boe, 1985 and Maffuli, 1992) and national hunt jockeys (Northcott, 1998).

To highlight the magnitude of fluid and energy restriction the data for 6 Senior England International boxers 24-hours pre and 24-hours post weigh-in is presented in Table 3. Fluid intake during the 24-hour period prior to the official weigh-in was 1.2 ± 0.5 l. This increased by 38 % to 3.2 ± 1.5 l during the 24-hour period post weigh-in prior to competition. A 24 % increase in energy intake was also observed from pre weigh-in 1051± 901 kcal to 4411 ± 1217 kcal post weigh-in. Steen and McKinney (1986) reported a similar increase in energy intake from pre weigh-in 334 kcal to 4214 kcal post weigh-in for a 54 kg wrestler.

Table 4. Changes in body weight for Senior and Junior England international amateur boxers over a 24-hour period immediately prior to and following the official weigh-in.

Group and weight class	**24-hour pre official weigh-in (kg)**	**body weight over weight class limit (%)**	**Official weigh-in (kg)**	**24-hour post official weigh-in (kg)**	**Increase in body weight pre-contest (%)**
Senior (n = 8)					
48	48.4	.8	47.9	48.7	1.6
51	52.0	2.0	51.0	53.1	4.1
54	54.9	1.7	53.8	56.4	4.8
57	58.1	1.9	56.9	58.3	2.5
60	60.9	1.5	60	61.5	2.5
75	76.5	2.0	74.9	84.0	12.1
81	82.3	1.6	80.6	84.2	4.4
91	92.3	1.4	90.9	93.6	3.0
Means (SD)		*1.6 (.4)*			*4.4 (3.3)*
Junior (n = 9)					
45	45.6	1.3	44.8	47.9	6.9
54	54.9	1.7	53.9	57.2	6.1
54	54.7	1.3	54.0	55.7	3.1
57	57.6	1.1	56.6	58.3	3.0
60	61.2	2.0	59.9	65.5	9.3
60	60.5	.8	59.8	63.0	5.3
64	64.6	.9	63.9	65.9	3.1
69	70.5	2.2	68.9	71.4	3.6
75	75.2	.3	74.8	75.5	.9
Means (SD)		1.4 (.4)			5.1 (2.3)

Recovery period

The existence of a recovery period between the Official weigh-in and competition commencing provides a window of opportunity for the boxer to restore fluid balance and optimise carbohydrate stores. The data contained in Table 4 shows that 2 hours prior to the weigh-in both Senior and Junior boxers body weight was 1.6 ± 0.4 % and 1.4 ± 0.4 % above the competition weight limit, respectively. Following a 24-hour recovery period prior to a Dual international (competition format that requires a boxer to weigh-in and compete only once) the Senior boxers increased body weight by 4.4 ± 3.3 % and the Junior boxers by 5.1 ± 2.3 %. Scott et al. (1994) recorded a similar increase in body weight (4.9 ± 2.4 %) amongst 668 college wrestlers following a 20-hour recovery period. Despite average values being similar between Senior and Junior boxers it is evident that significant individual variability exists between boxers of the same age group in relation to the amount of weight gained during the recovery period. The two highest increases in body weight were for the Senior 75 kg boxer (12.1 %) and Junior 60 kg boxer (9.3 %). Weight gains of this magnitude cannot occur during multi-nation type tournaments were the boxer is required to make the competition weight limit prior to each contest. Under this competition format weight gains are set at ~2 to 3 % body weight. The data contained in Table 4 clearly shows that the principle underpinning the weight classification system, making competition fairer by minimising differences in body weight between competitors, is not being adhered to. A similar observation was reported by Herbert and Ribisl (1972) in their review of wrestling, stating:

> *'As in many sports, the practical application of the rules does not always measure up to the principle upon which they are founded'. (p.416).*

Integral to the principle of matching boxers in relation to body weight is the assumption that maximum punching force is related to body weight. The recent development of boxing dynamometers has shown this assumption to be correct (Karpilowski et al., 1984; Smith 1998). Therefore, in the pursuit of fairness and the need to minimise the risk to a boxer's health, large discrepancies between boxers in terms of body weight immediately prior to competition should be avoided. The data also highlights that Junior boxers experience large fluctuations in body weight during a period of growth and maturation. Only one study to date has reported an eating disorder linked to weight making in junior boxers (Lovett, 1990). In this case study a 15 year-old flyweight boxer was reported to have become bulimic in his attempt to suppress his body weight in order to continue to box domestically at 51 kg.

Hydratory status

Urine osmolality has been shown to be a useful marker of hydratory status (Armstrong et al., 1994; Shirreffs and Maughan, 1998). In amateur boxing the following urine osmolality categories have been developed to indicate the level of dehydration: well hydrated < 399 $mOsm \cdot kg^{-1}$; hydrated 400-799 $Osm \cdot kg^{-1}$; dehydrated 800-1199 $mOsm \cdot kg^{-1}$ and severely dehydrated > 1200 $mOsm \cdot kg^{-1}$ (osmolality scale developed as part of the ABE World Class Programme, unpublished) (reference required) To highlight the challenge to a boxers hydratory status a selection of osmolality values are presented from competition and training. Table 5 shows a range of osmolality values recorded for Senior England International amateur boxers across 12 weight categories from two multi-nation tournaments. In Competition (A) first morning urine osmolality samples were collected over a 10 to18-day period (number of samples dictated by boxers level of success). The data shows that only the 67 kg and 91 kg boxers achieved any sustained period of fluid balance but neither boxer won a medal. The remaining 10 boxers all experienced at least 1 urine sample > 1000 $mOsm \cdot kg^{-1}$, with 3 out of the 6 medallists recording at least 1 urine sample > 1200 $mOsm.kg^{-1}$. Indeed, the 81 kg boxer had a mean urine osmolality value of 1177 ± 73 $mOsm \cdot kg^{-1}$ and won a gold medal. Similar findings were recorded for Competition (B) where only the 91 kg boxer showed any prolonged period of fluid balance but again this boxer did not win a medal. All boxers from the remaining 11 weight categories recorded at least 1 urine sample > 1000 $mOsm \cdot kg^{-1}$, with 3 out of 7 medallists recording at least 1 urine sample > 1200 $mOsm \cdot kg^{-1}$. The high urine osmolality values recorded in both competitions support previous data identifying the key role rapid fluid loss strategies play in enabling a boxer to make the weight (Table 2). The data contained in Table 6 shows the urine osmolality values recorded for Senior England international amateur boxers during an overseas and domestic training camp. In relation to the overseas training camp first morning urine osmolality samples were recorded over a 7-day period. Only 2 out of 17 boxers maintained a urine osmolality value < 1000 $mOsm \cdot kg^{-1}$, with 3 boxers recording a value > 1300 $mOsm \cdot kg^{-1}$. The major focus for the overseas camp was to address technical issues with each boxer and not weight reduction. The high urine osmolality values may be explained by a number of boxers staying within an agreed weight limit above their competition weight by choosing to increase energy intake at the cost of restricting fluid intake.

Table 5. Urine osmolality values recorded immediately prior to and during two multi-nation competitions (Comp) for Senior England international amateur boxers.

Comp	Osmolality ($mOsm·kg^{-1}$)	Weight class (kg) 48	51	54	57	60	63.5	67	71	75	81	91	91+
(A)	Means	910	1036	902	954	979	692	645	956	949	1177	566	857
	SD	111	220	270	222	264	270	117	236	210	73	170	145
	Range	650-1072	567-1213	509-1330	444-1186	519-1258	241-1072	449-843	376-1228	430-1188	1043-1267	354-849	484-1122
	Number of observations	15	10	11	11	15	12	15	18	17	18	11	18
	Medal won	Bronze				Bronze			Gold	Gold	Gold		Gold
(B)	Means	857	1171	1197	1008	1088	1169	890	1040	1139	962	793	961
	SD	101	61	96	125	135	55	199	122	266	84	17	186
	Range	695-1032	1099-1260	984-1293	720-1123	899-1252	1067-1242	611-1107	744-1191	445-1330	824-1063	781-806	543-1198
	Number of observations	9	6	9	8	8	9	6	11	10	7	2	12
	Medal won	Silver		Bronze		Bronze	Gold		Silver	Silver			Gold

These urine osmolality values are higher than those reported by Shirreffs and Maughan (1998) who compared Senior international amateur boxers (775 ± 263 $mosm·kg^{-1}$) and weight lifters (777 ± 254 $mOsm·kg^{-1}$) with non-weight classified athletes (627 ± 186 $mOsm·kg^{-1}$) during an 11-day overseas training camp. Urine osmolality data recorded during the 4-day domestic training camp are also higher than those recorded by Shirreffs and Maughan (1998). Only 3 out of 17 boxers maintained a urine osmolality value < 1000 $mOsm·kg^{-1}$, with 3 boxers recording values > 1200 $mOsm.kg^{-1}$. It is evident from these ese data that the majority of Senior England international boxers do not maintain fluid balance during training, despite often being several weeks away from competition. Urine osmolality data for Junior England boxers is limited. However, the data contained in Table 7 shows that during a 3-day domestic training camp 3 out of 4 boxers provided at least 1 urine osmolality value > 1000 $mOsm·kg^{-1}$, again suggesting an inability to maintain fluid balance during training. Urine osmolality recordings were taken first thing, usually between 6.45 a.m.-7.15 a.m., following an overnight fast. Urine samples were injected into an Osmometer and results fed back to the boxer and coach within 10 minutes. It is important to point out that the daily urine osmolality value does not take into account the re-hydration strategy undertaken during the recovery period. The high osmolality values indicate an attempt made by the boxer to enter a weight cateogory below their natural body weight. It does not directly reflect the hydratory status at the point of the boxer entering the ring.

Post contest blood lactate

The effects of different methods of scoring and contest format on post competition blood lactate values for Senior England international boxers are shown in Table 8. High post contest blood lactate values (> 8.0 $mmol·l^{-1}$), irrespective of the method of scoring or contest format, highlights the intense nature of competition and identifies the critical role played by anaerobic glycolysis in sustaining ATP resynthesis during an amateur contest. The post bout blood lactate value of 12.8 ± 3.0 $mmol·l^{-1}$ (impression scoring, 3 rounds x 3-minutes) was similar to 13.46 $mmol·l^{-1}$ recorded for 5 West German Senior amateur boxers (Kindermann and Keul, 1977). The reduction in post contest blood lactate values from 12.8 ± 3 $mmol·l^{-1}$ (impression scoring, 3 rounds x 3-minutes) to 9.5 ± 3 $mmol·l^{-1}$ (computerscoring, 3 rounds x 3-minutes) may be related to changes in training methods and tactical strategy (Smith, 1998). Radical changes to the contest format in 1997 (computer scoring, 5 rounds x 2-minutes) resulted in post blood lactate values decreasing to 8.6 ± 5 $mmol·l^{-1}$. In general, the contest strategy during this period (1997 to 1999) was based upon adopting a cautious start over the first 3 rounds with an increase in high-intensity

Table 6. Urine osmolality values recorded during overseas and domestic training camps for Senior England international amateur boxers.

Camp	Osmolality	Weight class (kg)																
	(mOsm·kg^{-1})	**48**	**48**	**51**	**51**	**57**	**57**	**60**	**60**	**69**	**69**	**75**	**81**	**81**	**81**	**91**	**91**	**91**
Overseas	Means	672	1053	925	1107	952	916	929	956	1170	1068	1037	729	1089	1080	819	1253	1112
	SD	205	103	346	31	205	251	209	72	86	139	157	258	409	125	272	140	125
	Range	387-955	855-1158	278-1301	1069-1146	608-1208	357-1099	568-1128	875-1069	1029-1290	835-1216	829-1220	208-985	264-1349	856-1174	498-1197	998-1431	871-1267
	Number of observations	7	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	7
Domestic	**Osmolality (mOsm·kg^{-1})**	**48**	**48**	**51**	**51**	**57**	**60**	**60**	**60**	**64**	**69**	**69**	**69**	**69**	**69**	**75**	**91+**	**91+**
	Means	1057	898	810	806	733	1071	1044	1007	923	1041	957	1132	1127	793	1131	966	964
	SD	110	216	354	180	398	51	40	46	75	101	67	158	12	275	93	63	208
	Range	895-1133	745-1051	492-1126	545-931	275-999	996-1113	992-1084	954-1043	837-981	938-1176	862-1012	965-1281	1112-1138	407-1021	998-1217	885-1040	821-1203
	Number of observations	4	2	4	4	3	4	4	3	3	4	4	3	4	4	4	4	3

activities (punch rate and dynamic footwork) over the final 2 rounds (Smith, 1998). The current contest format (computer, 4 rounds x 2-minutes) has resulted in further changes to training methods and tactical strategy. Greater emphasis is now placed on the amateur boxer to perform more frequent repeated bursts of high intensity activity (punch rate and dynamic footwork) at an earlier stage of the contest. This change in approach may explain the higher post contest blood lactate values under the current contest format (13.5 ± 2 mmol·l^{-1}) compared to previous observations. The high post contest blood lactate values for Junior boxers (14.1 ± 2 mmol·l^{-1}) highlights further the intense nature of competition and identifies the need to integrate into an amateur boxers training programme specific sessions aimed at increasing a boxers anaerobic capacity. Interval pad work, such as 8 x 1-minute rounds with 1-minute recovery between rounds, has been shown to be the most effective method of stressing the anaerobic glycolytic energy system with lactate values frequently > 10 mmol·l^{-1} (Smith, 1998). This method of training is successful because the coach dictates the training intensity. The need to expose the amateur boxer to high levels of blood lactate in training (> 9.0 mmol·l^{-1}) was previously reported by Gosh et al. (1995). Anaerobic glycolysis is largely dependent on the availability of muscle glycogen (Maughan and Poole, 1981; Guezennec et al., 1993). However, previous data (Table 2) has highlighted that the weight making methods adopted by Senior England international amateur boxers may result in glycogen depletion if the post weigh-in recovery strategy does not address the need to consume sufficient carbohydrate. The phrase 'dead at the weight' is commonly used by boxers and coaches to describe impaired amateur boxing performance associated with glycogen depletion (Smith, 1994).

Heart rate analysis

Over the past 20-years technological developments in heart rate telemetry has enabled exercise physiologists to gain a useful insight into the physiological demands experienced by boxers during various phases of the training programme. During the final days prior to competition the role of 'conditioned' and 'open' sparring become increasingly important (Hickey, 1980). 'Open' sparring is a type of training that most closely replicates the physiological demands associated with competitive boxing. Figure 1 shows a typical heart rate response of a Senior England international boxer to 'open' sparring. It is evident that a high heart rate response is achieved during each 2-minute round. Recovery heart rate decreases between rounds and in rounds 3 and 4 the heart rate response goes above the maximum heart rate value recorded during an incremental run to exhaustion on a motorised treadmill. Previous research has estimated that 59 % of ATP resynthesis during a 120-second maximal uphill run

Table 7. Urine osmolality values recorded during a domestic training camp for Junior England international amateur boxers.

Camp	Osmolality ($mOsm \cdot kg^{-1}$)	Weight class (kg) 51	57	69	81
Domestic	Means	1221	1085	505	1063
	SD	46	71	260	73
	Range	1168-1253	1042-1167	282-791	980-1112
	Number of observations	3	3	3	3

on a treadmill was provided by aerobic sources (Hermansen and Medbo, 1984). Therefore, in order to compete at the required intensity for all four 2-minute rounds it is necessary for an amateur boxer to have a well-developed aerobic capacity.

SECTION 2

Estimation of body fat

Previous data contained in Table 2 has shown that Senior England international amateur boxers employ a variety of methods to decrease body weight. Modifications to training and energy intake during the gradual phase of weight cycling are aimed at reducing the amount of stored body fat. Table 9 shows the total (mm) and body fat (%) for Senior and Junior England international boxers using the 4-site skin fold method (Durnin and Womersley, 1974). A body fat of 9.1 ± 2.3 % and total skin fold of 22.3 ± 4.4 mm was recorded for the Senior boxers. These values are higher than those recorded for USA elite amateur boxers (6.9 ± 1.6 %) and wrestlers (7.9 ± 2.8 %) in Fleck (1983). A higher body fat (10.1 ± 2.6 %) and total skin fold (23.8 ± 5.9 mm) was recorded for the Junior boxers. This difference may be related to the maturation process and or the fact that Junior boxers will have spent less time practising their weight reduction strategies. Whilst the reasons for the differences between Senior and Junior boxers remain unclear what is apparent is the attempt made by Junior boxers to alter their body fat stores.

Blood profile

The continuous supply of oxygen to maintain aerobic ATP resynthesis during amateur boxing competition is vital and is dependent on a number of factors (Smith, 1998). An increase in blood hematocrit is observed when amateur boxers become dehydrated or undertake altitude training (Friedmann et al., 1999). Data contained in Table 10 shows that for both Senior (48 ± 2 %) and Junior (45 ± 2 %) England international boxers hematocrit values were within the normal range but slightly higher than those reported for Senior international German amateur boxers (Friedmann et al., 1999). Normal values were also recorded for haemoglobin (Senior 14.7 ± 1.0 $g \cdot dl^{-1}$ and Junior 14.5 ± 0.8 $g \cdot dl^{-1}$). However, a review of the range of haemoglobin values shows several boxers with values below the normal range. Possible reasons for the low values may be related to inappropriate weight making methods. Normal bilirubin (15.3 ± 6.2 $\mu mol \cdot l^{-1}$) and ferritin (63.3 ± 45.7 $ng \cdot ml^{-1}$) values were recorded for the Senior group. However, Child et al. (2000) reported that following intense amateur boxing training Senior England boxers experienced a significant increase in red blood cell destruction that was not matched by a parallel increase in red blood cell formation, with 2 boxers ferritin levels below 20 $ng.ml^{-1}$.

Lung function

Prior to the 2004 Olympic Games the International Olympic Committee-Medical Commission (IOC-MC) required athletes using β_2 agonists to provide clinical evidence to support their claims that they had asthma (Dickinson et al., 2005). Asthma and exercise-induced asthma are two conditions that may impair oxygen kinetics. Table 11 shows the lung function profile of Senior and Junior International amateur boxers pre and 10 minutes post an incremental run to exhaustion. Figures 2, 3, 4 and 5 show that both Senior and Junior boxers had no sign of asthma or exercise-induced asthma. Failure to identify any boxers exhibiting asthmatic symptoms

Table 8. The effect of different methods of scoring and contest format on post competition blood lactate values for Senior and Junior international amateur boxers.

Group	n	Year	Method of scoring	Contest format	Lactate value ($mmol.l^{-1}$)	Range ($mmol.l^{-1}$)	Time of sample post contest (s)
Senior	29	1987-1988	Impression	3 rounds X 3 mins	12.8 (3.0)	7.6-17.7	258 (64)
Senior	20	1989-1996	Computer	3 rounds X 3 mins	9.5 (3.0)	6.4-13.1	240 (73)
Senior	6	1997-1999	Computer	5 rounds X 2 mins	8.6 (3.0)	6.3-10.0	220 (60)
Senior	75	2000-2004	Computer	4 rounds X 2 mins	13.5 (3.0)	7.2-17.2	283 (67)
Junior	24	2000-2004	Computer	4 rounds x 2 mins	14.1 (2.0)	10.0-18.1	250 (43)

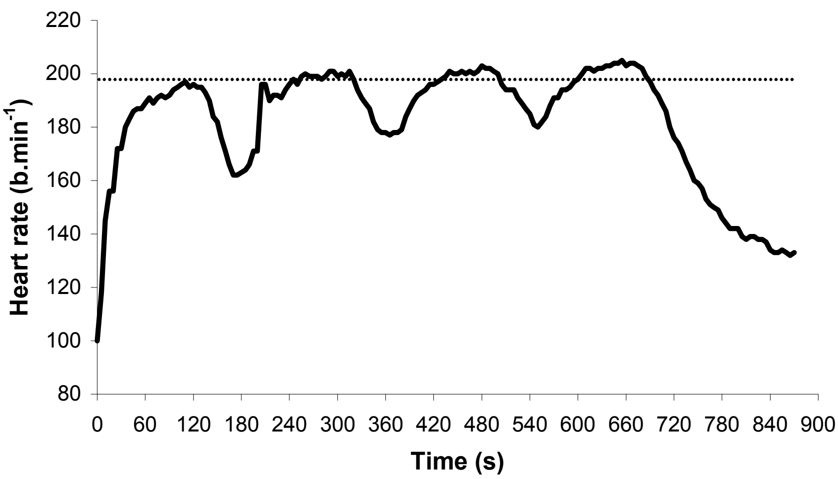

Figure 1. Typical heart rate response of Senior England international amateur boxer during 4 x 2 min Open sparring.

agrees with the findings of Dickinson et al. (2005) who reported no incidences of asthma or exercise-induced asthma amongst elite Senior boxers prior to the 2000 or 2004 Olympic Games.

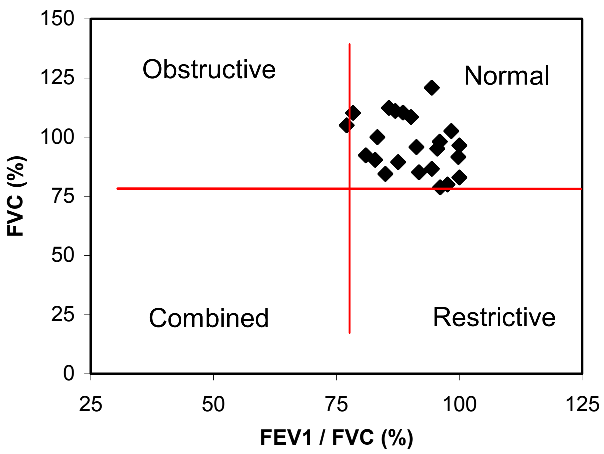

Figure 2. Millers diagnostic disease quadrant showing no symptoms of asthma amongst Senior England international amateur boxers.

Aerobic capacity

The requirement for an amateur boxer to have a well-developed aerobic capacity has been identified (Section 1). The absolute and relative VO_{2max} values for Senior and Junior international amateur boxers of a similar body mass are shown in Table12. A relative VO_{2max} value of 63.8 ± 4.8 ml.kg^{-1}.min^{-1} for the Senior boxers is similar to that reported for two groups of national Senior German amateur boxers prior to altitude training (Group 1 [n = 9]: 61.0 ± 4.9 ml·kg^{-1}·min^{-1} and Group 2 [n = 7]: 62.1 ± 3.6 ml·kg^{-1}·min^{-1}) Friedmann et al. (1999). A lower VO_{2max} value of 57.5 ± 6.9 ml·kg^{-1}·min^{-1} was reported for 8 Senior Italian middleweight (75kg) amateur boxers (Guidetti et al., 2002). Differences in VO_2max between groups may be related to the type of training undertaken and the mean body weight of boxers included in each study. This suggestion is supported by the work of Gosh et al. (1995) who reported lower VO_{2max} values in Indian Senior international amateur boxers from the heavier weight categories. A significantly lower relative VO_2max value of 49.8 ± 3.29 ml·kg^{-1}·min^{-1} was recorded for the Junior boxers. Such differences may be related to age, level of maturation or length of time engaged in aerobic training. Indeed, Bunc et al. (1996) reported a VO_{2max} value of 67.9 ± 5.9 ml·kg^{-1}·min^{-1} following extensive aerobic training for Junior elite triathletes. The importance of having a high aerobic capacity is supported by the data from a recent British Olympic medallist who had a relative VO_{2max} value of 69.1 ml·kg^{-1}·min^{-1}.

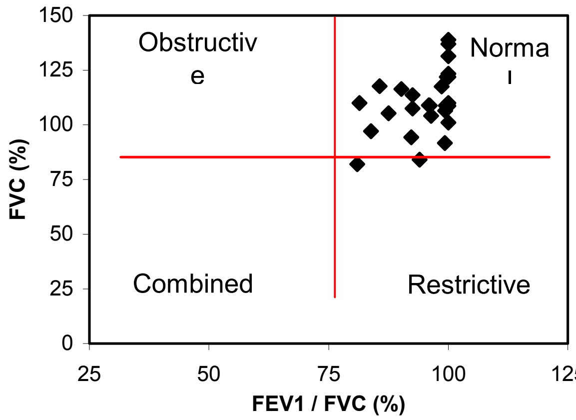

Figure 3. Millers diagnostic disease quadrant showing no symptoms of asthma amongst Junior England international amateur boxers.

A number of aerobic and anaerobic threshold measurements have been used to monitor training adaptations and set training intensities. The information contained in Table 13 shows the running velocity (km·hr^{-1}), heart rate (b·min^{-1}) and VO_2 (l·min^{-1}) response for Senior England international boxers at a blood lactate value of 2 mmol.l^{-1} and 4

Table 9. Skin fold values from 4-sites for Senior and Junior England international amateur boxers (Durnin and Womersley, 1974). Data are means (±SD) [Range].

Group	n	Bicep (mm)	Tricep (mm)	Sub-scapular (mm)	Supra- iliac (mm)	Total (mm)	Body fat (%)
Senior	23	2.8 (.4)	7.1 (1.6)	7.8 (1.9)	4.5 (1.2)	22.3 (4.4)	9.1 (2.3)
		[2.2-3.5]	[5.4-9.7]	[5.4-12.1]	[3.0-7.5]	[17.3-31.1]	[4.7-13.5]
Junior	73	4.2 (2.3)	7.1 (2.4)	7.5 (2.2)	5.1 (1.6)	23.8 (5.9)	10.1 (2.6)
		[2.2-12.6]	[2.4-13.4]	[2.8-15.8]	[2.9-10.9]	[15.0-44.0]	[5.0-17.7]

$mmol{\cdot}l^{-1}$. In relation to running velocity a speed of 10.43 ± 1.48 $km{\cdot}hr^{-1}$ and 13.38 ± 1.13 $km{\cdot}hr^{-1}$ was recorded at 2 $mmol{\cdot}l^{-1}$ and 4 $mmol{\cdot}l^{-1}$ respectively. A value at 2 $mmol{\cdot}l^{-1}$ of 2.7 ± 0.43 $l{\cdot}min^{-1}$ and 3.42 ± 0.52 $l{\cdot}min^{-1}$ at 4 $mmol{\cdot}l^{-1}$ for VO_2 was recorded with the 4 $mmol{\cdot}l^{-1}$ VO_2 as a percentage of VO_{2max} being 86 ± 6 %. Heart rate values were 151 ± 10 $b{\cdot}min^{-1}$ and 174 ± 8 $b{\cdot}min^{-1}$ for 2 $mmol{\cdot}l^{-1}$ and 4 $mmol{\cdot}l^{-1}$, respectively. The 4 $mmol{\cdot}l^{-1}$ reference point has been used to identify the maximum exercise intensity whereby a plateau in blood lactate can be achieved (Heck et al., 1985). This method of determining individual training thresholds has been successfully applied to the training programmes of Senior and Junior England international amateur boxers (Smith, 1998). The peak running velocity is identical to the value reported by Freidman et al. (1999) for German national amateur boxers (16.7 ± 1.0 $km{\cdot}hr^{-1}$).

Punch profile

The recent development of sport-specific dynamometers is an important step towards ecological validity in analysing amateur boxing performance (Smith et al., 2000). The data contained in Table 14 shows the maximum punching force for straight and hook punches, to head and body, of Senior international amateur boxers. From the data it is evident that in relation to straight punching at the head a higher punching force was recorded for the straight rear hand compared to the lead hand (lead hand 1722 ± 700 N vs rear hand 2643 ± 1273 N). A similar finding was recorded for straight punches thrown at the body (lead hand 1682 ± 636 N vs rear hand 2646 ± 1083 N). In relation to straight punching the observed differences in punching force between lead and rear hand may be related to an increase in the force generated by the legs (Fritsche 1978; Filimonov et al., 1983), degree of body rotation and the distance over which the long-range straight punch is thrown (Hickey, 1980). Also, the introduction of computer scoring has resulted in greater emphasis in training being placed on developing rear hand punching force (Smith, 1998). However, for the hook punches similar punching force values were recorded for lead and rear hand to the head (lead hand 2412 ± 813 N vs rear hand 2588 ± 1040 N) and body (lead hand 2414 ± 718 N vs rear hand 2555 ± 926 N). The increase in lead hand hook punching force compared to the straight lead hand may be attributed to the increase in body rotation associated with the technique of throwing a lead hand hook punch (Hickey, 1980). In comparison to previous data collected on elite England Senior international amateur boxers, the straight punching values are lower (Smith et al., 2000). The reason for this is somewhat unclear but may reflect a greater number of boxers included in the data presented in Table 14. A higher average rear hand straight peak punching force of 3427 ± 811 N for Australian

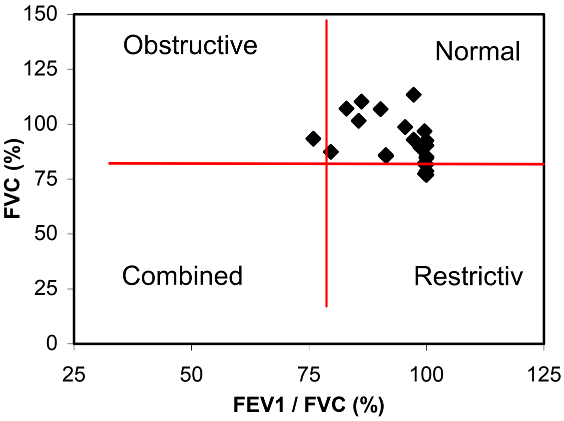

Figure 4. Millers diagnostic disease quadrant showing no symptoms of exercise-induced asthma amongst Senior England international amateur boxers.

Table 10. Blood profile of Senior (n = 19) and Junior (n = 26) England international amateur boxers. Data are means (±SD) [Range].

Group	Hematrocrit (range 40-54 %)	Haemoglobin (range 13.5- 18 $g.dl^{-1}$)	Bilirubin (range 0-21 $\mu mol.l^{-1}$)	Ferritin (range 20-250 $ng.ml^{-1}$)
Seniors	48 (2)	14.7 (1.0)	15.3 (6.2)	63.3 (45.7)
	[42-54]	[13.1-16.0]	[3.0-15.7]	[20-203]
Juniors	45 (2)	14.5 (.8)		
	[43-52]	[12.9-16.1]		

Table 11. Lung function profile pre and post VO_{2max} for Senior and Junior international amateur boxers. Data are means (±SD).

Group	n	Pre VO_{2max} FVC (l)	Pre VO_{2max} FEV_1 (l)	Pre VO_{2max} PEF ($l.min^{-1}$)	10 minutes post VO_{2max} FVC (l)	10 minutes post VO_{2max} FEV_1 (l)	10 minutes post VO_{2max} PEF ($l.min^{-1}$)
Seniors	23	4.7 (.7)	4.3 (.7)	589 (127)	4.5 (.8)	4.3 (.7)	623 (121)
Juniors	26	4.4 (.9)	4.15 (.7)	549 (92)	4.3 (.9)	4.2 (.9)	551 (92)

Senior international amateur boxers was reported (Walilko et al., 2005). However, this comparison should be treated with caution as Walilko et al. (2005) study had a low number of subjects (n = 7) with 2 boxers being super heavyweights (classified as > 91 kg).

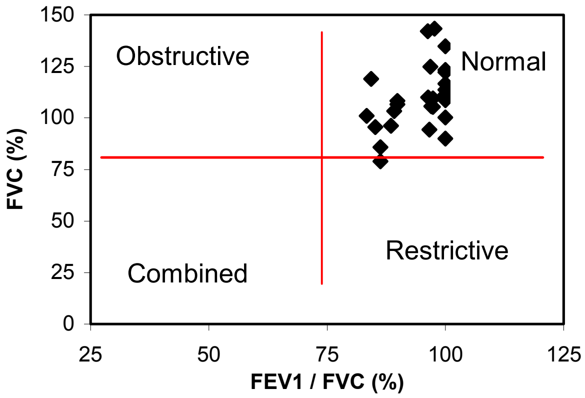

Figure 5. Millers diagnostic disease quadrant showing no symptoms of exercise-induced asthma amongst Junior England international amateur boxers.

The ability to throw repeated punches of sufficient force is a key component of success in amateur boxing (Smith, 1998). The number of punches thrown per round is dependent on a boxer's style and the tactics employed throughout a contest. From video analysis of competitive bouts a punching sequence was developed that required the boxer to throw 76 straight punches, incorporating single, 2-punch and 3-punch combinations with lead and rear hands, over 4 x 2-minute rounds on a boxing dynamometer (Smith et al., 2000). These data are contained in Table 15 and shows a total punching force of 388113 ± 102020 N per 4 x 2-minute simulated contest. The punch force data per round shows a similar value for each of the first three rounds (Round 1 96144 ± 26798 N, Round 2 96173 ± 25098 N and Round 3 95935 ± 24661 N) with an increase evident in the final round (Round 4 99861 ± 26898 N).

CONCLUSION

Energy supply during a 4 x 2-minute amateur boxing contest is provided through the inter-play between anaerobic and aerobic energy systems. The important role of anaerobic metabolism is reflected in a peak mean punching force of 2646 ± 1083 N for a single punch, delivered in < 60 milliseconds (Smith and Dyson, 1996), and high post contest blood lactate value (Seniors: 13.5 ± 2 $mmol \cdot l^{-1}$ and Juniors 14.1 ± 2 $mmol \cdot l^{-1}$). A high relative VO_{2max} value of 63.8 ± 4.8 $ml \cdot kg^{-1}.min^{-1}$ reflects the aerobic challenge to the amateur boxer competing over four 2-minute rounds. Impaired oxygen carriage was not evident from the tests for asthma and exercise-induced asthma or abnormalities within the blood haematological profile. However, following several months of intense training, ferritin stores were shown to decrease below the normal range in a limited number of boxers. In most cases, except for the super heavyweight category, England international amateur boxers select a competition weight below their natural body weight and reduced body weight accordingly. A gradual and rapid phase of weight reduction was identified during a 21-day period prior to the weigh-in. A variety of active and passive methods of weight loss were identified, with the crucial role of rapid fluid loss highlighted over the final 3-days. The implications on hydratory status of employing this method of weight loss were reflected in the high urine osmolality values (>

Table 12. Absolute and relative VO_{2max} values for Senior and Junior England international amateur boxers. Data are means (±SD) [Range].

	n	Body mass (kg)	Absolute VO_{2max} ($l.min^{-1}$)	Relative VO_{2max} ($ml.kg^{-1}.min^{-1}$)
Seniors	23	62.5 (10.8)	3.99 (.5) [3.06-5.12]	63.8 (4.8) [53.1-70.0]
Juniors	26	65.3 (13.0)	3.25 (.7) [2.37-4.70]	49.8 (3.29) [43.2-56.2]

(NB: Senior data collected using off-line Douglas bag method (Smith, 1998) and Junior data predicted from the 'Aero' test (Wilkinson et al, 1999).

Table 13. Running velocity, heart rate and VO_2 at 2 mmol·l^{-1} and 4 mmol·l^{-1} reference points for Senior England international amateur boxers (n = 23).

Blood lactate	Variable	Means	SD	Range
2 mmol·l^{-1}	Velocity (km·hr^{-1})	10.4	1.5	7.5-13.7
	Heart rate (b·min^{-1})	151	10	128-168
	VO_2 (l·mim^{-1})	2.7	0.4	1.9-3.55
4 mmol·l^{-1}	Velocity (km·hr^{-1})	13.38	1.13	11.4-16.0
	Heart rate (b·min^{-1})	174	8	151-184
	VO_2 (l·min^{-1})	3.42	0.52	2.51-4.3
4 mmol·l^{-1}VO_2 as a % of VO_{2max}		86	6	67-97
Peak running velocity (km·hr^{-1})		16.7	0.6	15.5-18.1
Maximum heart rate (b·min^{-1})		194	7.6	184-209

1000 mOsm·kg^{-1}) recorded during training and competition. The existence of a recovery period between the official weigh-in and competition commencing provides the amateur boxer with a window of opportunity to re-address any fluid or energy deficiencies. However, insufficient time or the adoption of an inappropriate strategy could result in an amateur boxer entering the ring in a dehydrated and glycogen-depleted state, leading to impaired performance and an increased risk to health.

Practical guidelines

- Prior to the start of each competitive season a boxer's competition weight class must be identified. In most cases the weight class remains the same for domestic and international contests. However, for certain boxers there may be the requirement to compete at a lower weight category for internationally championships. Major domestic and international competitions must be identified and an appropriate training programme established. A programme of laboratory testing and field support
- work, both in training and at competition, also needs to be established. The need for role clarification between athlete, coach and service provider is vital (Collins et al., 1999). In relation to body weight specific training weight bands need to be established for the 'gradual' and 'rapid' phases of weight loss. The time scale for weight reduction needs to be identified, along with the active and passive methods of weight loss. A post weigh-in fluid and energy replacement strategy must be developed to re-address any imbalances caused by the weight making process. This strategy of replenishment must be practised in training. Finally, time must be set aside following each competition cycle for reflection. What worked? What did not work? What needs to change in the future?

ACKNOWLEDGMENTS

The author is pleased to acknowledge the support of the England Amateur Boxing Association. In particular, Mr Ian Irwin, ABE Coaches, members of the ABE World Class Support Programme and boxers. In addition, the author also wishes to acknowledge the intellectual contribution of Professor Tudor Hale from the University of Chichester and Mr. Simon Northcott in the preparation of the manuscript.

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Table 14. Maximum single punch force for the straight and hook punches, to head and body, of Senior England international amateur boxers.

Force		Straight lead to head	Straight rear to body	Straight rear to head	Straight rear to body	Lead hook to head	Lead hook to body	Rear hook to head	Rear hook to body
Absolute (N)	$\overline{X}$	1722	1682	2643	2646	2412	2414	2588	2555
	SD	700	636	1273	1083	813	718	1040	926
Relative(N·kg)	$\overline{X}$	25	25	39	39	36	35	38	37
	SD	9	8	17	15	11	9	13	12

Subject characteristics: n = 29, Means (±SD) age= 21 (2) yrs, height = 1.74 (.08) m, mass 67 (10) kg, over competition weight 6.2 (3.7) %.

Table 15. Endurance punching force calculated from 76 straight lead and rear hand punches per round, to the head target, by Senior England international amateur boxers (n = 29). Data are means (±SD).

Force	Round 1 (N)	Round 2 (N)	Round 3 (N)	Round 4 (N)	Combined Total (N)
Total	96144 (26798)	96173 (25098)	95935 (24661)	99861 (26898)	388113 (102020)
Per punch	1265 (352)	1265 (330)	1262 (324)	1314 (353)	

Subject characteristics: n = 29, Means (±SD) age= 21 (2) yrs, height = 1.74 (.08) m, mass 67 (10) kg, over competition weight 6.2 (3.7) %.

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KEY POINTS

- Senior England international amateur boxers decrease 6.0-8.3 % (7.0 ± 0.8 %) body weight over a 21-day pre-contest period by employing passive and active weight making methods.
- Urine osmolality values >1000 $mOsm \cdot kg^{-1}$ are recorded during training and competition.
- Senior and Junior England international amateur boxers experience high post contest blood lactate values (*Seniors* 13.5 ± 2 $mmol \cdot l^{-1}$ and *Juniors* 14.1 ± 2 $mmol \cdot l^{-1}$ under the current 4 rounds x 2-minute contest format.
- Senior England international amateur boxers have a high relative VO_{2max} of 63.8 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$
- Senior England international amateur boxers have a straight and hook punch force >2400 N, except for the straight lead hand to the head and body.

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