

**Strength and conditioning for professional boxing:
recommendations for physical preparation**

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Abstract

Professional boxing is a popular pan-global sport that attracts considerable interest and revenue. It is a high-intensity sport that requires a range of well-adapted physiological characteristics as likely pre-requisites for successful performance. Serious consideration has been given to medical aspects and potential health risks from partaking in training and competition. However, there are no comprehensive sources of applied sport science research on the preparation of professional boxers for competition. In this review we present research from physiology and strength and conditioning to form a knowledge base for those involved in preparing professional boxers for competition.

Key words: Boxing, physiology, strength, combat, force, physical preparation

Introduction

Professional boxing is regarded as one of the most physically and mentally demanding sports in the world, yet despite this recognition and popularity, professional boxing has received little attention within the scientific literature. A PubMed search (23rd July 2015), for “Professional Boxing” returned 44 results, the majority of which had a specific focus on brain injury. In contrast to this low volume of academic interest, professional boxing contests have the potential to generate considerable interest and local and international revenue. Indeed, in a May 12th 2015 article in *The Guardian*, unverified reports estimated revenue in excess of \$500 million for a single professional boxing event. To date, however, there are no comprehensive scientific reviews or practical recommendations for the preparation of professional boxers for training and competition. The reasons for the lack of applied sport science research are likely diverse and beyond the scope of this article, but it is surprising given the growing body of scientific research in sports with similar world-wide interest.

A professional boxer's preparation is complicated by the requirement to include conditioning, strength and boxing specific training within a short time frame before a contest, usually 8 to 12 weeks (figure 1). Given the complexity of the training process and time demands, professional boxers and their trainers would benefit from evidence-based guidance to supplement existing training practices. The preparation of a boxer should be considered in context, with a clear understanding of the determinants of successful performance. Therefore, this article will provide an overview of the rules governing professional boxing competition, highlight a variety of theory and research relevant to the demands of professional boxing and provide practical recommendations for testing, and developing strength and conditioning programmes.

INSERT FIGURE 1 HERE

Boxing competition and successful performance

Similar to most body mass restricted combat sports, professional boxers are required to weigh in and meet their contest body mass 36 to 24 hours prior to competition. Lower standard contests might comprise of 4 x 2 min with a 1 minute interval between rounds, but an elite professional boxing contest can last up to 12 x 3 minute rounds. During the one minute interval between rounds a trainer is allowed in the ring to offer coaching instructions; they might also wish to provide ice, iced-towels and water but stimulants (which include carbohydrate-electrolyte beverages) are prohibited. Perhaps the most well-known way to win a boxing match is by knockout. A knockout is usually caused by a single blow but is often preceded by repeated high force legitimate blows. In the case of a head strike, a knockout is caused by acute neurological trauma, due to large magnitudes of internal torque applied to the cerebellum and brain stem (14). A second way to win a contest is by technical knockout. This occurs when the referee has decided that the opponent is in no position to defend their-self or is being outclassed. This is most likely preceded by demonstration of attacking skills and accompanying high force blows, in this circumstance it is common for the corner to 'throw the towel in' if they are concerned for their boxer. However, a professional boxer's primary aim is not to knockout their opponent, but demonstrate superior physical, technical and tactical skills; these are paramount in the third way to win a boxing contest, by a points decision. Points are awarded using subjective criteria but are based on the boxers attacking and defensive skills, the relative importance and content of these broad categories are both judge and contest specific. In this circumstance preparation of the professional boxer is crucial to improve their chance of winning a round and the whole contest as poor physical fitness would limit performance capacity.

Physiological demands

Data regarding physiological demands and exercise to rest ratios in professional boxing are not available in scientific literature, however based on our experience it is reasonable to assume, along with data relating to punch volume and intensity (33), force-velocity (30) and impulse-momentum relationships (28), that professional boxing comprises repeated high-intensity actions interspersed with brief periods of low intensity actions or recovery. These high-intensity actions are derived from electrical, chemical and mechanical physiological processes, most of which require rapid hydrolysis and phosphorylation of adenosine triphosphate via non-oxidative energy pathways. However, due to the repeated high-intensity demands these needs cannot be met in full by non-oxidative sources. Hence, energy derived primarily through oxidation of muscle glycogen supports a large proportion of adenosine triphosphate hydrolysis and phosphorylation to meet systemic demand, the magnitude of which is likely a determinant of professional boxing performance. The assertion that performance demands a large contribution from oxidative energy pathways is supported by peak oxygen uptake values (derived from incremental exercise tests) of $58 \pm 7 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in Italian middleweight amateur boxers (13) and up to $64 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in senior-international amateur boxers (32); and $> 60 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in our unpublished observations of elite professional boxers. Simulated amateur boxing has been reported to elicit large energy demands (4, 31) (approximately 80 to 90% peak oxygen uptake) with 77%, 19% and 4% of energy derived from aerobic, phosphocreatine and anaerobic glycolysis energy pathways respectively (9) that suggests a reliance on muscle glycogen as a primary fuel source.

Impact of physiological demands on technical ability

Professional boxing is primarily a technical and tactical sport; external demands such as the requirement to attack or evade determines physiological strain. A boxer must perform appropriate attacking or defensive actions at an intensity that does not exceed their ability to control the ring using footwork skills and the precision of their attacking or controlling punches. If a boxer can perform at an intensity that induces low physiological strain, then they might have the potential to control the contest and avoid fatigue. However, if the external demands imposed on a boxer induce physiological strain, or when successive high intensity actions compromises rates of recovery, fatigue will probably limit subsequent performance (5).

In professional boxing fatigue might manifest as a transient decline in punch impulsiveness, frequency or precision, poor decision making and limited defensive actions. Repeated high-intensity actions are associated with a decrease in phosphocreatine (10), reduced activity or inhibition of glycolysis (11), increased cellular hydrogen ions (31), altered calcium sensitivity (2), impaired sodium-potassium pump function (2) and skeletal muscle damage (15). However, performance is suggested to be an integrative multifactorial process (29) and it is likely that a combination of mechanisms determine short term recovery (26). When boxers are required to perform above their critical intensity (8) or with limited recovery, physiological perturbations in skeletal muscle, cardiovascular functioning, metabolic strain and pain sensation (22) integrate to alter perceived exertion, voluntary activation of the neuromuscular system and manifest as fatigue (26). Skilful boxers can control the pace of the contest and, if required, limit the attack of an opponent by using footwork to control the ring and direction of activity, defensive tactics such as holding, and the 1-minute interval between

rounds to recover. These tactics allow at least partial restoration of homeostasis, achieved by speeding recovery (e.g. repaying an oxygen debt) or limiting physiological strain in the first instance.

Practical applications: Conditioning training recommendations

Of primary importance for many professional boxers is the development of aerobic capability. Athletes with well-developed aerobic energy systems are likely to recover from high intensity activity faster (4) or perform at intensities that do not exceed their critical intensity (17). Precise quantification of aerobic capacity and an understanding of physiological characteristics of a professional boxer is important to monitor changes and programme individual training intensities.

INSERT FIGURE 2 HERE

Data derived from assessments (figure 2) might assist in identifying strengths and areas for improvement relating to energy system dominance, running economy, substrate utilisation and provide heart rate and rating of perceived exertion data required to prescribe and monitor training intensities. It is important that conditioners understand the physiological characteristics of their athletes, develop methods to assess characteristics and use information derived from these tests to design specific training programmes to develop these qualities. We recommend preparing professional boxers by developing aerobic capability in a sport-specific manner, based upon their strengths and areas for improvement. Using information derived from valid and reproducible tests it is possible to tailor training programmes in an appropriate way to develop physiological capabilities, while boxing training (bag work, pads, sparring) might develop these more specifically.

There is compelling evidence that High Intensity Interval Training (HIIT) improves aerobic capacity (7, 20, 25, 27). The mechanisms by which adaptations occur are complex and it is unclear as to what type of stimulus and interventions provide optimal benefits for a particular physiological characteristic. Three possible sites for the main effects of HIIT are the active myocytes (utilisation and cellular buffering), capillary structures (extraction) and myocardium (delivery). It is likely that HIIT induces central, peripheral and neuromuscular adaptations with training demands being influenced by 9 variables (7). Despite this complexity, HIIT's strength is in its variety of application and it is clear that the choice of HIIT should be dictated by a boxer's individual strengths and areas for improvement, training and competitive schedule and additional environmental/lifestyle constraints.

INSERT TABLE 1 HERE

Table 1 provides an overview of conditioning recommendations for a typical 12 week preparatory period. Sprint interval training demands the recruitment of high-threshold motor units and is a potent stimulus for rapid improvements in skeletal muscle oxidative capacity (12) making this type of training ideal for improvements in force production and aerobic capability early in the training phase. These peripheral adaptations should be progressed by using high-intensity interval training for around 6 weeks to stimulate myocardial adaptations and muscle capillarization that contribute to improvements in aerobic capacity (27). Finally, a taper phase 2 weeks before competition, which also includes a reduction in boxing specific technical training volume is recommended. This reduction should be athlete specific but a volume decrease of around 40 to 60% of total training load is recommended (6). It should be noted that the aim of this training structure is not intended to replicate the potential time-motion demands of boxing. Rather, evidence-based interventions are used as stimuli for improvements in aerobic capacity and to a lesser extent mechanical force production. Adaptations in these areas can be utilised to facilitate increases in boxing specific technical

training volume and more specifically used as base for high quality open sparring, which requires an adequate standard of aerobic fitness. To this extent conditioning training is usually constrained by the coaches' decision to increase the volume of open sparring, however, a period of around 6 weeks of focussed conditioning is typical. Thus optimising training stimuli and adaptation using evidence-based training prescription is paramount in the preparation of a professional boxer.

Effective punching

Striking an opponent with a clean 'hit' irrespective of force will gain favour with judges and potentially disrupt an opponent's acute strategy. More forceful single punches or repeated high-force punches are intended to position an opponent for a sustained attack (leading to contest termination) or display skill, technical ability and dominance during the contest. Forceful punches are also used as a defensive tactic to limit the advance of an opponent and their attacking strategy.

In principle three factors contribute to the effectiveness of a single punch. Firstly, movements in sprint running, karate or boxing typically involve fast skeletal muscle actions highlighting the importance of developing large magnitudes of force in short periods of time (1). Secondly, the momentum of the punching arm is important and has been demonstrated to be a key variable contributing to the impulsiveness of a punch (28). Finally, a second pulse in muscle activation is required on impact and has been defined as “stiffening” to create “effective mass” (23). These factors (the rate of force development (RFD), momentum, second pulse) are determined by effectiveness of a boxers ability to generate force via hip, knee and ankle extension, rotation of the trunk and arm extension (21).

It is likely that the impulse generating capacity of a boxer is important and is intrinsically linked to segmental momentum during force generation and, at impact. Indeed, reductions in momentum of the punching arm prior to impact are suggested to explain around 95% of the variance in peak impulse at impact during rear-hand straight punches (28). The main contributor to the impulsiveness of a punch might be hand speed, as it explains around 40% of the variance in hook and straight punching force. Therefore, a goal of strength training should be to increase the momentum of the punching arm, resulting in greater impulse on the target.

Practical applications: Strength training recommendations

An obvious way to increase momentum of the punching arm is to increase mass (from Newtonian physics). It is common across most sports for practitioners to target muscular hypertrophy in the off-season or early mesocycles to stimulate increases in physiological cross-sectional area, building a foundation for strength development. However, body mass classifications make hypertrophy training difficult to implement and can complicate dietary practices, therefore improving rate of force development should be a priority for the practitioner.

The rate at which force is developed likely to be influenced more by the capacity to produce force irrespective of the phenotypical myosin heavy chain content of muscle fibres alone (3); suggesting that neuromuscular factors are integral to the rate of force development. The development of hand speed by inducing favourable adaptations in series-elastic components and the neuromuscular system is therefore a key variable in the prescription of strength training for professional boxers. Therefore, we recommend the selection of appropriate assessment methods, some of which are presented in figure 3, to programme multi-planar

exercises, with carefully structured external loads that enable the boxer to train with attention appropriately focused on strengths and areas for improvement.

INSERT FIGURE 3 HERE

Table 2 provides examples of general strength and movement training for professional boxers. Development of the hip extensors, in particular function of the Gluteal musculature, is important and is recognised for its role in athletic ability. These can be trained using key lifts such as using squats, deadlifts and Olympic lifts where there is a focus on developing forceful hip extension. In addition, assistance exercises such as dumbbell floor press, pull ups, plank rows and others detailed in table 2 and 3, are also recommended for their role in developing the force generating capability of a professional boxer, as well as improving robustness and facilitating increases in boxing specific technical training load.

In conjunction with strength and movement training we also recommend professional boxers incorporate exercises that require rapid rates of force development. Jump height depends on impulse (18) and as such the rate and magnitude of external-mechanical force development (24). Strength training designed to improve peak force combined with low-external load jump training to improve the rate of force development (24), should have positive transfer to force production during punching. Table 2 provides examples of jump training that might be utilised by trainers.

Practical applications: Mobility and trunk training

Effective force transmission is derived from optimal force-coupling and length-tension relationships of active musculature, however, boxers are at risk of ineffective performance and injury due to dysfunctional movements and poor force production. Frequent physical

impacts caused by blows to the body, collisions, structural imbalances and overuse can result in microtrauma. The resulting inflammatory response might lead to fascia scar tissue over-time and subsequent muscular dysfunctions. Physical impacts and collisions are unavoidable in professional boxing. However, our observations suggest that structural imbalances are common and are likely a greater cause of ineffective force transmission.

Synergistic force transmission occurs across myo-tendinous junctions (16) and summation, or 'force transmission' is essential to create effective musculoskeletal sequencing and punching force. Malalignment within the kinetic chain might contribute to suboptimal length-tension relationships, constraining peak force and causing it to occur at a more acute joint angle. This is an obvious concern when force is generated in the upper body as a limited reach caused by insufficient range of motion and reduced force at near full elbow extension might impair the effectiveness of a jab or rear hand punch. It is important to recognise that these limitations, might restrict the ability to summate force causing a reduction in momentum and decreasing subsequent impulse applied to the target. Table 4 provides priority areas, methods of assessments and basic techniques to help boxers improve mobility and force transmission.

It is likely that pelvic and trunk speed and stability contribute to increased hand speed during a punch. During rotation, a stretch of the trunk allows for a more forceful rotation through utilisation of the stretch-shortening cycle (SSC) (19) generating torque at the shoulder joint and enhancing force transmission through the elbow extensor musculotendinous unit. Indeed, punches require multiple angular displacements through sagittal, frontal and transverse planes throughout the full range of punch variations, with the punch type determining segmental force contribution and a countermovement before initiation of a punch increasing the capability to produce an impulsive punch (30). Exercises designed to improve the capability

of the trunk to provide stability and contribute to the effectiveness of punching are detailed in general in table 2, depicted in figure 4 and presented as part of a 12 week training programme in table 3.

INSERT FIGURE 4 HERE

Practical applications: Effective mass

A double "peak" in muscle activity is evident during striking actions. Stiffening of the body at impact through isometric activity is postulated to create "effective mass" and reduce energy loss (23). Stiffening can be developed using pad and heavy bag training in technical training as well as using effective cues such as "popping" of the hips and "stiffen up" at the end range during strength exercises that might induce double activations and stiffening. Moreover, isometric contractions paired with a rapid relaxation can be beneficial in improving end range stiffening. Trunk training can also be used as means to facilitate improvements in the generation of "effective mass" by increasing isometric force production (bracing) at impact.

Conclusion

Research regarding the physical preparation of professional boxers for competition is limited. Professional boxing comprises repeated high-intensity actions interspersed with brief periods of low intensity activity or recovery. These demands require large contributions from both oxidative and non-oxidative energy pathways. As such, a range of physiological characteristics should be assessed using valid and reproducible tests. Variations in carefully prescribed high-intensity interval training tailored to the strengths and areas of improvement elucidated from physiological assessments can be used to develop aerobic capacity. Punches are intended as both offensive and defensive actions, and a combination of rapid whole body rate of force development, resulting momentum of the arm and isometric muscle activity at

impact contributes to forceful punches. The use of multi-planar exercises with aim of improving rotational range of movement, rate of force development and segmental sequencing is recommended to develop an effective punch. A boxer who receives individualised and evidenced-based recommendations at all stages of preparation for a contest is an athlete who enters the ring with less risk of incurring serious medical conditions in the short-and long-term. A limitation of this review is that it generalises across body mass categories, gender, ethnicity and performance standards. As such, scientific support and research for professional boxing should be encouraged, particularly by governing bodies in the interests of athletes' health, international audiences, media, and medical and scientific communities.

List of tables and figures

Table 1: Conditioning recommendations for professional boxing

Table 2: General Strength training exercise recommendations. D.B. = dumbbell; M.B. = medicine ball; K.B. = Kettlebell; CMJ = countermovement jump;

Table 3: Specific strength training programme for professional boxers

Table 4: Recommended areas of focus for improving range of motion and force transmission.

SMR = Self myofascial release; TFL = tensor fascia latae; L-P-H-C = Lumbar, pelvic, hip complex.

Figure 1: Overview of typical 12 week preparatory phase for professional boxing

Figure 2: Assessment, prescription and monitoring recommendations for conditioning. RPE = rating of perceived exertion; HR = heart rate; LT = lactate threshold.

Figure 3: Assessment, prescription and monitoring recommendations for strength training.

Figure 4: A = Medicine ball lunge woodchop; B = Medicine ball punch; C = Landmine punch.

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