BOXING - Strength and Conditioning for Professional Boxing

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BOXING

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INTRODUCTION TO THE SPORT

Similar to most weight restricted combat sports, professional boxers are required to "weigh in" and meet their contest weight 36 to 24 hours prior to competition. A (national to world championship) standard professional boxing contest usually takes place in a square "ring' 4.88 m^2 to 6.10 m^2 over 12, 3 minute rounds, with a 1 minute interval between rounds. As such a professional boxing contest can last up to 47 minutes (12 × 3 minute rounds = 36 + (11 × 1 = 11) = 47 min); however, at a minimum, lower standard contests might comprise of 4 × 2 min (total 8 min boxing). Boxers must wear a protective mouth guard; shorts and genital protection are also worn but protective head gear is not permitted. Boxing gloves are required and weigh 227 g for flyweight (52 kg) to welterweight contests (67 kg) and 283 g for heavier weight classifications. During the one minute interval between rounds, a chief "second" (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.

A professional boxing contest is overseen by a referee and typically three judges; in the majority of occasions the winner of a contest is confirmed by those individuals. The most well known, although most unlikely way to win a contest is by knockout (estimated 6% of all wins). A knockout is usually preceding by a single or successive number of high force legitimate blows that in the case of a head strike results in acute neurological trauma likely caused by large magnitudes of internal torque applied to the cerebellum and brain stem (areas of the brain involved in conduction and control of motor and sensory information) (Heilbronner e*t al.,* 2009). It may also come from a blow to another part of the body, applied with such force that the boxer falls to the ring floor and is unable to continue the contest as deemed by the referee. In the former case, one of the two ringside medical doctors must examine and monitor the boxer for signs of serious brain injury, and reference their physical and mental state to that prior to the weigh in and/or contest and the structural integrity of the brain as determined by recent magnetic resonance imagery scan.

Another way to win a contest is by technical knockout. In this instance a boxer has failed to satisfy the referee that they are in a position and condition to defend their self, or they are being outclassed by their opponent. This decision is usually made following a period of sustained high force blows and demonstration of attacking skill. If in this instance a boxer's corner feels they are being outclassed and they deem it unsafe for the bout to continue, they might "throw the towel in". In the case of a technical knockout, a medical examination is required by the ringside doctor as per a knockout decision. In both instances, it would seem that the aim of professional boxing is to induce considerable physical damage to an opponent, such that it causes acute neurological or other injury. Indeed, boxers who sustain repeated forceful blows to the head are at risk of post concussion syndrome in the days after the event or chronic traumatic encephalopathy (Heilbronner e*t al.,* 2009) in the long term.

These risks have led to several bodies issuing statements declaring that professional boxing be banned (American Medical Association, 1999 www.ama-assn.org/ama1/pub/upload/mm/443/csaa-99.pdf; Australian Medical Association, 2007 https://ama.com.au/position-statement/boxing-1997-reaffirmed-2007; World Medical Association, 2003 www.wma.net/en/30publications/10policies/b6/). Sport scientists must abide by clear ethical guidance set by their governing body or affiliation that states that the safety of an athlete is paramount. Providing scientific support to enable a boxer to inflict damage and potential neurological trauma on another human should be considered very carefully within ethical guidelines. These above concerns are alleviated slightly by routine medical assessments and in the case of well-trained athletes who are able to cope with the physical demands. However, there are specific instances, such as weight loss, dehydration and rehydration strategies that if insufficient, will place the athlete at risk of serious injury; also if within a contest a boxer is clearly being outclassed. It is reasonable to assume that in the majority of circumstances, professional boxers do not intend to cause life-threatening and long lasting injuries to their opponent.

Professional boxers compete to demonstrate superior physical, technical and tactical skills; these are paramount in the third way to win a boxing contest, by a points decision, a situation in which most professional boxing contests are decided. In major title bouts, three well experienced independent judges score each round, giving 10 points to the winner of the round and 9 points or less to loser. At the end of the contest the points are totalled and each judge declares a winner; the actual winner is the boxer who has the majority of the judge's decisions. 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, nutrition and mental preparation would likely limit performance capacity and place a boxer at risk of serious medical conditions. Moreover, the short period in which boxers prepare for competition (usually 8, 10 or 12 weeks) has to be optimised. This leaves little room for error and no time for malpractice. Thus, training and preparation needs to be carefully thought through, planned and delivered, with safety and wellbeing of paramount concern.

Athletic demands

Needs analysis

Davis, Benson, Pitty, Connorton and Waldock (2015) reported that elite standard amateur boxers initiate attacking or defensive actions every 1.4 seconds over a 3-minute round with 77%, 19% and 4% energy derived from aerobic, phosphocreatine and anaerobic glycolysis energy pathways, respectively, during three semi-contact 2-minute rounds (Davis, Leithäuser and Beneke, 2014). A well-developed aerobic capability is a likely possible pre-requisite for success; aerobic capacities ($\dot{V}O_{2max}$) in the range of 57.5 to 69.0 ml·kg^{-1}·min^{-1} have been reported in senior amateur boxers

(Guidetti, Musulin and Baldari, 2002; Smith, 2006) and can exceed 70 $ml \cdot kg^{-1} \cdot min^{-1}$ in elite professional boxers (unpublished observation from European champion). Smith (2006) reported that senior amateur boxers had a 21% greater $\dot{V}O_{2max}$ compared to junior-international standard boxers, suggesting aerobic capabilities of boxers might differ due to maturation and experience. Senior competitions are scheduled for 3 × 3 minutes, whereas junior bouts are limited to 3 × 2 minutes. The longer contest duration and training practices required for senior boxers might explain the differences between fighters. Blood lactate concentrations have been reported for both senior (13.5 ± 2.0 $mmol \cdot L^{-1}$) and junior (14.1 ± 2.0 $mmol \cdot L^{-1}$) boxers after four 2-minute rounds (Smith, 2006).

Boxers attempt to strike opponents cleanly, to gain favour with judges and disrupt an opponent's strategy. Increased force of single punches or punch combinations are also intended to cause a knockout, position an opponent for a sustained attack (leading to contest termination) or display dominance over an opponent. A punching action appears to take ~60 ms, with fist speeds around 9 $m \cdot s^{-1}$ (Piorkowski, Lees and Barton, 2011; Nakano, Iino, Imura and Kojima, 2014). Peak punch forces of ~2500 N have been observed at impact (Smith, 2006); however, magnitudes might differ depending on punch type, weight classifications and skill level of the boxer (Smith, 2006; Piorkowski e*t al.,* 2011). Smith (2006) reported an accumulated punching force of 388113 ± 102020 N during simulated boxing activity, where 76 punches (single, 2- and 3-punch combinations) over 4 × 2 minute rounds were thrown. Mean punching force was ~1200 N, suggesting that reproducing forceful punches during competition is an important factor.

Depending upon the experience of a professional boxer, they might have as little as 6 weeks or as much as 16 weeks to prepare for a contest. In other cases they might not know when they are next competing and accept an offer to compete at short notice (1 to 2 weeks); these instances make the task of planning training difficult. Moreover, some professional boxers only choose to train when "on camp"; thus, they detrain in the weeks they are inactive, make poor nutritional choices and consequently increase fat mass, all of which are undesirable for training and performance.

A typical 12-week training camp structure is illustrated in Table 22.1. The first 6 weeks are usually focused around physical and mental training, whilst technical training load is increased slowly. Between 6 and 8 weeks (4 weeks before competition), technical training and open sparring becomes a priority and strength and conditioning takes a complementary role. The key to an effective strength and conditioning programme within this 6- to 8-week period is to increase physical capacity such that the boxer can cope with increased training demands of open sparring. In the remaining 6 to 8 weeks an effective strength and conditioning programme should complement technical and tactical demands of sparring. Thus establishing a good relationship and line of communication with the coaching team is essential. A professional boxer's preparation in this period relies on good quality sparring but is somewhat dependent on the sparring partners' and coaches' availability. Having the ability to adapt a training plan at short notice to take advantage of windows of trainability or limit training load is essential.

This structure is often constrained by lifestyle, financial and logistical demands in the developing professional boxer who has yet to establish a full-time income from the sport. Younger boxers often meet financial obligations by undertaking physically active jobs such manual labour and mail delivery, which needs to be taken into account when programming. As the standard of the boxer increases, these demands are limited, until the athlete can earn a full-time living from boxing. These circumstances often impose limits on the basic foundational practices required for high performance. Indeed, initial assessments of the boxers' and teams' understanding of nutritional strategies, such as hydration and fuelling for training sessions; daily, weekly and camp training structure; training history; injury awareness and common illness are elements that should be considered prior to delivery of any special interventions. Improvements in these areas can have

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large benefits on training quality, adaptation and therefore performance, and focusing on areas such as mobility and injury prevention can reduce the number of training hours missed due to injury and illness.

Movement dysfunctions

Boxers maintain a similar stance throughout their technical work that typically shortens the hip muscles, and they amplify this shortness with hours of running at submaximal intensities. Hip flexor tightness can cause many injuries and dysfunctions, including lower back pain, and can limit gluteal strength. Hip and trunk torque contributes to punch force; therefore, mobilising and strengthening this area can improve performance as well as reduce the likelihood of injury.

Shoulder mobility

"Hands up, chin down" is often the coaching point to a defensive guard, requiring rounding and a shrug of the shoulders. When boxers throw thousands of punches per week, the anterior shoulder musculature and trapezius muscles can become over-active. This alone can cause shoulder mobility issues for boxers. These issues are often compounded by large volumes of strength-circuit based exercises like press ups and shoulder press which are common in traditional boxing training methods. Poor shoulder mobility often creates over-active anterior deltoids and upper trapezius, causing the middle and lower trapezius to become weak, which affects the natural movement of the shoulder and arm. This can also cause shoulder impingement, rotator cuff weakness and lower back injuries.

Rotational mobility

Rotational mobility is needed to transfer force from "foot to fist" when delivering punches.

However, tightness in muscles across the thoracic spine can limit rotation, causing the Quadratus Lumborum (QL) to play an overactive role during rotation, and can cause lower back pain. To make beneficial long-term changes and reduce compensatory patterns of the QL, boxers need to improve thoracic and core rotation range of movement.

Gluteal strength

Many boxers have underdeveloped gluteal strength due to time spent in their boxing stance and large endurance-type running volumes. Gluteal strength is an important contributor to forceful hip extension and rotation needed during running, jumping and more importantly, punching. The gluteal muscles have the potential to be the largest contributor to hip extension and rotation; however, many boxers have under-active gluteal musculature due to mobility and activation problems. Stronger gluteal muscles can improve a boxer's ability to engage and strengthen the core musculature, which can help protect against injuries to the lower back muscles and improve punching force.

Laboratory based fitness testing

Anthropometric profiling

As boxers compete in weight categories, characterisation of body composition is important for determining tissue contribution to body mass. Quantification of segmental lean tissue and fat mass might form the basis for nutritional interventions and strength training. For example,

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- Arms straight above head
- Upper leg parallel with floor
- Knees do not go past toes
- Neutral head position

- Stick is parallel with floor
- Knees are pushed to outside
- Torso even – not leaning to one side
- Arms are straight, no bend at elbow

Figure 22.1 Overhead squat analysis

relative lean trunk mass is an important contributor to indices of punch force. Thus, retaining and increasing lean trunk mass is important for boxing performance. Bioelectrical impedance and skin fold assessments are valid assessments of body composition and should be performed at regular intervals. Weekly assessments are recommended throughout a specific training camp (i.e. 12 week competition period) and bi-weekly assessments when boxers are not training for a specific bout. These assessments should be coupled with pre-defined weight targets set by the coaching team.

Overhead squat

This is a popular test that has been used to assess dynamic flexibility, core strength, balance and neuromuscular control. This test can identify muscular imbalances and movement dysfunction in both upper and lower extremities, making it a useful and practical test.

Single leg squat

This transitional movement assessment has been used as a reliable and valid assessment of lower extremity movement patterns. Knee valgus, hip position and trunk leans can be an indicator of joint motion, muscle activation and overall neuromuscular control.

Table 22.1 Basic movement analysis

Check point	*Point*	*Compensation*	*Probable overactive muscles*	*Probable underactive muscles*	*Cause for concern rating and possible causes*
Knee	3	Move Inward (Valgus)	Adductor Complex Bicep Femoris Tensor Fascia Latae (TFL) Lateral Gastrocnemius Vastus Lateralis	Medial Hamstring Medial Gastrocnemius Gluteus Medius Gluteus Maximus Vastus Medialis Oblique Anterior Tibialis Posterior Tibialis	This is a common issue in boxers as the stance requires an external rotation of the hip, causing TFL to be overactive. This causes underactive gluteals, meaning hip extension and rotation can become sub-optimal. This makes the adductor complex overactive in super-compensation.
	6	Move Outward	Piriformis Bicep Femoris Tensor Fascia Latae Gluteus Minimus	Adductor complex Medial Hamstring Gluteus Maximus	Not as common as valgus due to the over activity of the adductor complex
Lumbar pelvic hip complex	2	Excessive Forward Lean	Soleus Gastrocnemius Hip Flexor Complex Piriformis Abdominal Complex	Anterior Tibialis Gluteus Maximus Erector Spinae Intrinsic Core Stabilisers	Very common in boxers due to overactive muscles in the lower limbs. Hip flexor tightness is a result of hip flexion in a boxing stance and large running volumes. Gastrocnemius and soleus tightness could be a result of being on the toes for the majority of training.
	1	Low Back Arches	Hip Flexor Complex Erector Spinae Latissimus Dorsi	Gluteus Maximus Erector Spinae Intrinsic Core Stabilisers Hip Flexor Comples	Common in boxing due to the tightness of the hips and core muscles. Also, the latissimus dorsi is often overactive as plays a big role during combination punching and boxers develop these by using pull ups.
	Opposite to 1	Low Back Rounds	Hamstrings Adductor Magnus Rectus Abdominis External Obliques	Gluteus Maximus Hamstrings Intrinsic Core Stabilisers	Common due to tightness of the hamstrings as they deal with large volumes of eccentric loading during technical, sparring and fitness training.
	3	Asymmetrical Weight Shift	Adductor Complex Tensor Fascia Latae Gastrocnemius Soleus Bicep Femoris Gluteus Medius (opposite side)	Gluteus Medius Anterior Tibialis Adductor Complex (opposite side)	This happens in almost all boxers due to a "traditional" boxing stance requiring more weight transferred on the rear foot.

Proof

- Foot flat and pointing straight forward
- Knee aligns with second toe
- Hips remain parallel with floor
- Upper body stays in neutral position

- Hips pushed back
- Knees flex online with toes
- Spine remains in neutral position
- Controlled forward lean

Figure 22.2 Single leg squat analysis

Countermovement jump and squat jump

Jump height assessments are useful to assess lower body impulsiveness (Ruddock and Winter, 2015), which is a component of force transmission during punching (Piorkowski e*t al.,* 2011). Countermovement jump (CMJ) and squat jump (SJ) height calculated from flight time using a photocell system (Microgate, Bolzano, Italy), provide valid assessments of jump height (Glatthorn e*t al.,* 2011). Typically a boxer will jump similar heights in CMJ and SJ, which is indicative of poor eccentric utilisation in the lower body. Since high force punches are preceded by a pre-stretch in the lower body and core musculature, the ability to utilise eccentric activity is important for force transfer.

Landmine punch throw test

This test assesses the ability to produce high velocities in a movement pattern similar to a rear-hand punch. An Olympic barbell (20 kg) is inserted into a landmine attachment, which positions the bar at angles between 40–60 degrees, depending on stature. Positioned at shoulder height on the same side of the rear foot with the elbows flexed, boxers are instructed to rotate their trunk and produce maximal effort to throw the bar as fast as possible. Velocities are measured by a linear position transducer (GymAware Optical Encoder, Kinetic, Canberra, ACT). This provides the practitioner with instant feedback on the peak velocity (m/s) for each repetition. The GymAware is placed on a metal weight plate directly underneath where the participant will perform the landmine throw, and attached 15 cm from the end of the barbell.

Participant takes a split (boxing) stance with the bar held by the rear hand, on line with the shoulder. From a stationary position, the participant rapidly rotates to throw the bar as fast as possible. Participant must keep feet planted throughout the movement. Following five repetitions, switch stance to perform test on opposite hand.

Figure 22.3 Landmine punch throw

Boxers should complete five attempts on each arm at 20 kg, 25 kg, 30 kg, 35 kg and 40 kg. Participants should have 2 minutes rest between each incremental load. Peak velocity is plotted against load for investigation of the load-velocity profile. Peak velocity can be assessed according to normative data (Table 22.2) and linear regression can be used to estimate zero load velocity, indicative of hand speed, and zero velocity load, indicative of maximal isometric strength.

Lactate profile

This test comprises 3 min of running at 5 to 6 fixed intensities on a motorised treadmill interspersed with 1 min of recovery, during which a fingertip capillary blood lactate sample is acquired. The test can be combined with collection of expired air to enable the assessment of substrate utilisation, oxygen uptake and running economy. The trend line of running speed and blood lactate can be analysed to determine breakpoints from linearity, thus the running speed at the first and second lactate turn-points. These can be used to benchmark performance and to set heart rate training zones. Typically a 3-zone model demarked by the first and second turn-point is suitable for a boxer's training prescription.

30:15 test treadmill test

This is a modified version of the 30:15 intermittent shuttle running test (Buchheit, 2008) as boxers find decelerating and turning at high speed difficult, which increases the risk of injury. The treadmill test follows the same speeds, running time and recovery period as the original test but does not require any change in direction. The test procedures are reported in detail elsewhere (Buchheit, 2008). Briefly athletes are required to run for 30 s at a fixed speed before a 15 s passive

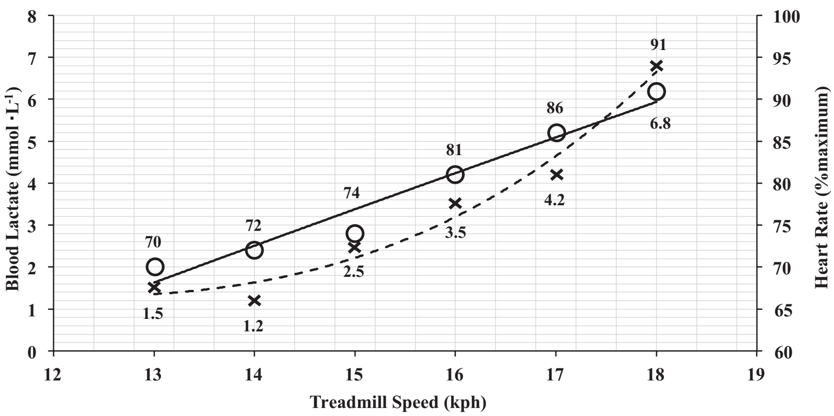

Figure 22.4 Representative data of a lactate profile obtained from a professional boxer. O = % maximum heart rate. X = Blood lactate (mmol·L^{-1}). Lactate turn-point 1 = 14 kph. Lactate turn-point 2 = 17 kph.

recovery period. The test starts at a speed of 8 kph and increases by 0.5 kph each 30 s stage. The test is terminated when the athlete can no longer maintain the desired speed. The last completed stage in addition to duration (s) run at the final speed is recorded.

Field-based test alternatives 60 seconds press-up test

The ability of boxers to produce force and the rate at which force is developed is important for successful performance (Nakano e*t al.,* 2014). This press-up test is a suitable to assess muscular strength-endurance, a surrogate of maximum voluntary force production. Boxers are required to start prone with hands positioned perpendicular to the shoulder joint; elbows and knees fully extended with the trunk parallel to the floor. Elbows are flexed until the chest and thighs contact the floor. The participant returns to the start position by extending the elbows. This action is counted as one repetition; participants are encouraged to repeat as many of these actions as possible in 60 s.

Medicine ball backhand throw

This test assesses the ability of the boxers to develop force in a movement pattern similar to a rear-hand punch. A 3 kg medicine ball is positioned at shoulder height on the same side of the rear foot (e.g. right foot to the rear, medicine ball held in right hand) with the elbows flexed. Boxers are instructed to rotate their trunk and produce maximal effort to throw the ball as far as possible from a marked location on the floor. Each boxer should be instructed to rapidly rotate their body proximal to distal whilst fully extending the elbow before releasing the ball. The first point of ball to ground contact is recorded as the distance thrown (m).

Incremental shuttle tests: 30:15 intermittent running test and Yo-Yo Intermittent Recovery Test Level 1

These tests are used to assess the ability to recover from high intensity aerobic exercise, similar to the demands imposed on a boxer during competition. Both are incremental exercise tests whereby running speed is increased each minute. Methods describing the test procedures are detailed elsewhere (Bangsbo, Iaia and Krustrup, 2008; Buchheit, 2008).

Table 22.2 Reliability and assessment standards for professional boxers

Test	*Reliability (CV%)*	*Poor*		*Adequate*		*Good*		*Excellent*	
Countermovement jump (cm)	5.2	< 35		40–44		45–49		> 50	
Squat Jump (cm)	3.2	< 30		35–39		40–44		> 50	
Landmine punch throw peak velocity (m/s)	2.5	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
20 kg		< 3.56	< 3.54	3.57–3.97	3.55 to 3.76	3.98–4.26	3.77–3.96	> 4.28	> 3.98
25 kg		< 3.11	< 3.0	3.11–3.51	3.01–3.3	3.52–3.65	3.31–3.48	> 3.69	> 3.5
30 kg		< 2.75	< 2.67	2.76–2.99	2.68–2.94	3.0–3.28	2.95–3.08	> 3.3	> 3.09
35 kg		< 1.92	< 1.80	1.93–2.4	1.81–2.32	2.41–2.67	2.33–2.56	> 2.68	> 2.56
40 kg		< 2.17	< 2.02	2.18–2.32	2.03–2.09	2.33–2.61	2.10–2.34	> 2.65	> 2.42
Lactate profile		≤ 10		12		14			
Lactate turn-point 1 (kph)		≤ 13		15		17		≥ 15	
Lactate turn-point 2 (kph)								≥ 18	
30:15 intermittent treadmill test (peak speed (kph))	1.5	≤ 19.5		20–21.5		22–23		≥ 23.5	
Yo-Yo IRT L1 (m)	13.7	< 1600		1600–2000		2000–2400		> 2400	
30:15 intermittent shuttle test (peak speed (kph))	1.9								
60 s press-up test (reps)	9.3	< 60		60–70		70–80		> 80	
Medicine ball back hand throw	5.8	< 9		9–11		11–13			
Dominant (m)	8.2	< 8		8–10		10–12		> 13	
Non-dominant (m)								> 12	

Programming Maximising training adaptation

Boxers are required to make weight and train for competitive performance within a relatively short time (usually 8 to 12 weeks). A well developed aerobic capacity is integral for boxing performance and is also required to support an increase in physical and technical training load (Ruddock, Wilson, Thompson, Hembrough and Winter, 2016). Thus optimising physiological stimuli for adaptations in aerobic capacity through training and amplifying cell signalling is key.

Three main sites contribute to the effectiveness of aerobic metabolism; 1) active myocytes (oxygen utilisation and cellular buffering); 2) capillary structures (oxygen extraction) and; 3) the myocardium (oxygen delivery).

Rapid changes in the oxidative phenotype of skeletal muscle mediated via beneficial adaptations in mitochondrial enzyme activity have been reported after short periods of sprint interval training (Gibala and McGee, 2008). Specifically, 30 s all-out exercise is associated with acute-upregulated activity of AMPK, CAMPK, SIRT1, p53 and p38 MAPK, important signalling cascades, associated with the transciption co-activator PGC1-α which is a key regulator of mitochondrial biogenesis thus aerobic metabolism (Liang and Ward, 2006; Gibala e*t al.,* 2009). Furthermore, short-term training studies (2 and 6 weeks) provide evidence for changes in the maximal activity of Citrate Synthase, Beta-hydroxyacid Dehydrogenase, Cytochrome C Oxidase and Pyruvate Dehydrogenase (Burgomaster e*t al.,* 2008), key ezymes involved in aerobic metabolism.

All-out high-force exercise is likely required for professional boxers with advanced training histories, particularly in the early phases of training, since these individuals might require intensive training to activate singalling pathways to a sufficient level to induce effective adaptations (Yu e*t al.,* 2003). These peripheral (skeletal muscle) adaptations and perhaps improvements in muscle architecture, mechanical force generation and neuromuscular coordination combine to improve exercise tolerance but not aerobic capacity *per se* (Weston, Taylor, Batterham and Hopkins, 2014). Nevertheless, these adaptations provide the foundation for further improvements in and complement structural adaptations required for improvements in aerobic capacity in subsequent training phases.

Central cardiovascular adaptations, (left-ventricular function, end-diastolic volume, systemic vascular resistance, muscle capillarisation) thus improvements in cardiac output and delivery of oxygen to exercising muscle seems to be improved by high-intensity interval training lasting between 4 and 10 minutes at an intensity equivalent to 90% of maximum oxygen uptake repeated 4 to 6 times (Buchheit and Laursen, 2013a, 2013b). However, although integral to improvements in aerobic capacity and performance, beneficial structural adaptations reportedly take around 8 to10 weeks, much longer than sprint interval training (SIT) (Montero, Diaz-Cañestro and Lundby, 2015). Nevertheless, these types of sessions are also important in a boxer's perception of intensity, because they challenge the athlete to exercise in a physiological state close to maximum effort, thus preparing a boxer for performance, physically and mentally.

When boxers are required to improve aerobic capacity, we recommend a 3 week SIT period, to take advantage of rapid skeletal muscle remodelling, followed by 6 to 8 weeks of HIIT, to induce central cardiovascular adaptations, and finally a 2-week taper consisting of repeated sprint training.

Table 22.3 Example conditioning programme (adapted from Ruddock e*t al.,* 2016)

Weeks before competition	*Training phase*	*Example training session*	*Frequency*	*Intended physiological adaptations*
12 to 9	Oxygen extraction and utililisation	30 s all-out maximum effort, 3 min passive recovery, 4 to 6 repetitions	2 to 4 sessions per training week	Mitochondrial biogenesis, maximal activity of oxidative and non-oxidative enzymesProvide stimuli for recruitment of high-threshold motor units, co-ordination and rate of force development
8 to 3	Oxygen delivery	4 to 8 min at 85 to 95% maximum heart rate, 2 minute passive recovery, 4 to 6 repetitions	2 to 4 sessions per week for first 3 weeks1 to 2 sessions per week as sparring load increases	Improve cardiovascular capacity (stroke volume, cardiac output, muscle capillarisation, and systemic vascular resistance), delivery of O2, and enhance venous return
2 to 0	Taper	20 s all-out maximum effort, 10 s passive recovery, 4–8 repetitions, 1–2 sets, 5 min recovery between sets	1 to 2 sessions per week	Transfer adaptations to boxing specific activity profiles. Reduce accumulated fatigue. Maintain neuromuscular activity

Strength training

The force of a punch is dependent on the impulse-momentum relationship. The most obvious way to increase the momentum of the punching arm is to increase mass (from Newtonian physics) via muscular hypertrophy. However, weight classifications make hypertrophy training difficult to implement, and can be contradictory to nutritional interventions, which often induce a calorie deficit. Generating large magnitudes of force in a short space of time is the result of many integrated processes, including genetic factors, muscle fibre type composition, the ability of the nervous system to recruit motor units and the structure and ultra-structure of muscle (Andersen and Aagaard, 2006).

Furthermore, moderate to large correlations (r = 0.60 to 0.70) between jump height and landmine punch throw velocity, suggests boxers should concentrate on developing lower-body impulse (Ruddock and Winter, 2015). In consideration, strength training should be designed to improve peak force development, combined with low-external load jump training to improve rate of force development (McLellan, Lovell and Gass, 2011), resulting in a positive transfer to force production during punching.

Improving the strength of the hip extensors, in particular, function of the gluteal musculature, is important. These can be trained using key lifts such as squats, deadlifts, and Olympic-style lifts, where there is a focus on developing forceful hip extension. It is also important to develop force-production and transfer in the upper-body and trunk using multiple planes of movement.

Table 22.4 Progression of resistance exercise type for boxers

Exercise type	*Phase 1*	*Phase 2*	*Phase 3*	*Phase 4*
Hip Hinge	DB Romanian Deadlift	Romanian Deadlift	Sumo Deadlift	Deadlift
Squat	Overhead Squat	Goblet Squat	Box Squat	Back Squat
Vertical Press	Half Kneeling DB Press	Kneeling DB Press	Single Arm DB Press	DB Push Press
Horizontal Press	Press Ups	DB Floor Press	DB Chest Press	Bench Press
Vertical Pull	Band Pull Down	Banded Pull Up	Pull Up	Weighted Pull Up
Horizontal Pull	Suspension Row	Weighted Suspension Row	DB Row and Rotate	DB Prone Row

For the upper body, horizontal and vertical pushing and pulling exercises are required (see TAB) to target strength development. Careful selection of load, repetition and sets is important to limit muscular hypertrophy and prevent excessive strain on movements limited by mobility particularly around the shoulder.

A double "peak" in muscle activity is evident during striking actions (McGill, Chaimberg, Frost and Fenwick, 2010). This is a stiffening of the body at impact through isometric activity and is postulated to create "effective mass" and reduce energy loss. Effective mass is best developed using pad and heavy bag training in technical training. However, physical exercises with accommodating resistance or those encouraging end range stiffening can help improve effective mass. In addition, effective cues such as "popping" of the hips and "stiffen up" at the end range can help induce isometric activity.

We have also found that the lean mass of the trunk (*r* 90% CI = 0.65 to 0.94) has a large correlation with medicine ball throwing distance. During rotation, a stretch of the trunk allows for a more forceful rotation through utilisation of the stretch-shortening cycle (SSC), generating torque at the shoulder joint and enhancing force transmission through the elbow musculotendinous unit. In consideration, punches require multiple angular displacements with the punch type determining segmental force contribution and a countermovement before initiation of a punch increasing the capability to produce an impulsive punch. Therefore, we recommend a selection of multi-planar exercises that challenges the mobility and stability of the trunk to help develop rotational strength and speed of the core musculature.

Movement 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 because of dysfunctional movements and poor force production. This is due to repetitive movement patterns within a boxing stance and large training loads without the integration of movement and mobility training. There are various methods used to improve this, including dynamic/static stretching, proprioceptive neuromuscular facilitation (PNF) and movement training.

Shoulder and rotational mobility

The pectoralis major and anterior deltoid muscles are often overactive in boxers as their main functions are shoulder flexion and internal rotation; these actions are used during a punch. It is important to lengthen and release tension in these muscles as this can cause joint dysfunction, particularly around internal rotation of the humeral head. This can cause rotator cuff impingement, shoulder instability, bicep tendinitis and thoracic outlet syndrome. Due to the anterior muscles being overactive, posterior muscles around the shoulder joint can become inhibited. These include lower trapezius, rhomboids and rotator cuff muscles. The inhibition of these muscles can limit extension and external rotation of the shoulder with super-compensation from the lower-back muscles. Over-activity of the upper trapezius muscles can create tension in myofascial slings across the thoracic segment of the spine and can affect the ability to utilise thoracic rotation during punching actions. This results in a boxer instinctively laterally flexing the spine, causing over activity in the Quadratus Lumborum (QL), attached to L2-L5 of the spine. This is particularly common in the same side of the lead hand, due to limited rotation during the jab punch. Tightness in the QL can cause pelvic misalignment, affecting muscular activity in the lower extremities.

- ***Self-myofascial release*** – Massage ball over the pec, thoracic spine, latissimus dorsi
- ***Static stretches/floor exercises*** – Eagles, windmills, floor slides, prone TYWs, plank rows, latissimus dorsi stretch, quadruped thoracic rotation
- ***Dynamic movements*** – Yoga press-ups, dumbbell or suspension Y-raises, uni-lateral cable rows, half-split squat with trunk rotation, kettlebell row and rotate
- ***Hip mobility and gluteal strength***

A typical boxing stance requires the athlete to externally rotate the hips and have an open stance that causes pronation of the feet. Furthermore, they are required to rapidly extend/rotate the hips during a punch; however, they do not have the strength in their hip extensors so rely on knee valgus to contribute to force development. This causes lower extremity movement impairment, with tightness in the adductor complex, psoas, iliotibial band and tensor fascia latae. Boxers need to lengthen and release tension in these areas in order to activate and strengthen the key hip extensors. Furthermore, this tension can cause misalignment of the hips – resulting in lower back pain.

- ***Self-myofascial release*** – IT band, gastrocnemius, soleus, hip flexors
- ***Static stretches*** – kneeling hip flexor stretch, advance with rear foot elevated and trunk rotation or lateral flexion
- ***Dynamic movement*** – Prisoner split squat, reverse lunges, lunge and twist, spiderman and twist

Over activity of the hip flexor muscles creates pelvic misalignment and anterior tilt; this causes the gluteal muscle groups to be in a lengthened state and affects their ability to shorten and produce force. Furthermore, boxing requires good lateral movement and internal rotation of the hips. A major contributor to this is the gluteus medius muscle; however, this can be inhibited due to tightness in the adductor muscles. It should be noted that misalignment of the hips can contribute to asymmetries between left and right gluteal strength; therefore, unilateral exercises should be implemented in a boxer's training.

- ***Self-myofascial release*** – IT Band, TFL, piriformis
- ***Floor exercises*** – Banded side clams, banded glute bridges, single leg glute bridge, quadruped hip extension
- ***Dynamic movement*** – Walking lunges, front-foot elevated split squat, banded side-walks, ice-skaters, banded shadow-boxing

Conclusion

Successful performance in professional boxing is determined by a boxer's ability to control the contest. This is achieved by demonstrating superior offensive, defensive and ringmanship skills. A professional boxer must therefore possess a variety of technical skills supported by a wide variety of physical attributes. A large aerobic capacity is required to support physiological demands imposed by training and competition and can be developed mainly through intelligent programming of sprint and high-intensity interval training. A forceful punch is integral to contest control and is dependent on the impulse momemtum relationship. Strength training to develop hip and knee extension maximum force and rate of force development coupled with the core musculature training to improve torque through the hips and upper body should be a key focus for a professional boxer. In addition, improving range of motion and developing mobility of the shoulders and hip musculature will help improve force transmission from the foot to the fist.

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