The search for sport-specific tests in boxing: 
Strength, power and anaerobic measurements

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Boxningsidrotten utövas brett runt om i världen och för att tävla internationellt på mästerskap som världsmästerskapen och de Olympiska spelen behöver boxare vara vältränade. Ett verktyg för att uppnå detta är fysisk och fysiologisk testning för att mer metodiskt övervaka och planera träning. Syftet med denna uppsats är att studera sambandet mellan träningsvolym hos boxare, från en återkallning av antalet träningstimmar genomförda per vecka, och resultaten från fyra olika tester – upper body Wingate anaerobic test (UWAnT), countermovement jump (CMJ), hand grip strength (HGS) and isometric mid-thigh pull (IMTP). Valet av varje test diskuteras utifrån ett fysiologiskt perspektiv för att påvisa dess koppling till boxningsprestation. Testning bestod av ett testtillfälle som genomfördes under en tävlingsperiod och boxare som inkluderades var 16 herrar på seniornivå. Resultaten visade att antal träningstimmar genomförda under en vecka hade en svag korrelation med HGS (r=0.236), en stark korrelation med CMJ (r=0.570), en moderat korrelation till maximal isometrisk styrka i IMTP (r=0.343), en svag korrelation till relativ maximal isometrisk styrka i IMTP (r=0.189) och en star korrelation till maximal anaerob power, relativ maximal anaerob power och trötthetsindex i UWAnT (r=0.574, r=0.769 och r=0.641 respektive). I denna uppsats diskuteras även de tillämpade metoderna och den inkluderade gruppen för att studera dess samband till andra tester som skulle kunna förklara olika kvaliteter i en boxningsprestation. Baserat på resultaten i denna uppsats kan det konkluderas att HGS och IMTP inte kan förklara styrka i en boxningsprestation, vilket bör studeras vidare. Det kan även konkluderas att UWAnT och CMJ skulle kunna förklara anaerob power och kapacitet samt explosiv styrka i en boxningsprestation och kan därför anses vara relevanta tester för en boxningsprestation.

Abstrakt

Boxningsidrotten utövas brett runt om i världen och för att tävla internationellt på mästerskap som världsmästerskapen och de Olympiska spelen behöver boxare vara vältränade. Ett verktyg för att uppnå detta är fysisk och fysiologisk testning för att mer metodiskt övervaka och planera träning. Syftet med denna uppsats är att studera sambandet mellan träningsvolym hos boxare, från en återkallning av antalet träningstimmar genomförda per vecka, och resultaten från fyra olika tester – upper body Wingate anaerobic test (UWAnT), countermovement jump (CMJ), hand grip strength (HGS) and isometric mid-thigh pull (IMTP). Valet av varje test diskuteras utifrån ett fysiologiskt perspektiv för att påvisa dess koppling till boxningsprestation. Testning bestod av ett testtillfälle som genomfördes under en tävlingsperiod och boxare som inkluderades var 16 herrar på seniornivå. Resultaten visade att antal träningstimmar genomförda under en vecka hade en svag korrelation med HGS (r=0.236), en stark korrelation med CMJ (r=0.570), en moderat korrelation till maximal isometrisk styrka i IMTP (r=0.343), en svag korrelation till relativ maximal isometrisk styrka i IMTP (r=0.189) och en star korrelation till maximal anaerob power, relativ maximal anaerob power och trötthetsindex i UWAnT (r=0.574, r=0.769 och r=0.641 respektive). I denna uppsats diskuteras även de tillämpade metoderna och den inkluderade gruppen för att studera dess samband till andra tester som skulle kunna förklara olika kvaliteter i en boxningsprestation. Baserat på resultaten i denna uppsats kan det konkluderas att HGS och IMTP inte kan förklara styrka i en boxningsprestation, vilket bör studeras vidare. Det kan även konkluderas att UWAnT och CMJ skulle kunna förklara anaerob power och kapacitet samt explosiv styrka i en boxningsprestation och kan därför anses vara relevanta tester för en boxningsprestation.
Abstract

The sport of boxing is widely practiced around the world, and to compete internationally at the World championships and the Olympic games, boxers need a high fitness level and one of the tools used to achieve a high fitness level is physical and physiological testing for methodological monitoring and planning of training. The aim of this thesis was to study the relationship between training time in boxers, as in the recalled number of weekly training hours, and the results from four different tests, upper body Wingate anaerobic test (UWAnT), countermovement jump (CMJ), hand grip strength (HGS) and isometric mid-thigh pull (IMTP). The choice of each tests is discussed from a physiological perspective to show its association to boxing performance. Testing consisted of one testing session, which was held during a competition period, and 16 male boxers (age=23±5 years) in the senior ranks were included. The results showed that the number of weekly training hours had a weak correlation to HGS (r=0.236, r²=0.056), a strong correlation to CMJ(r=0.570, r²=0.325), a moderate correlation to peak isometric strength in IMTP (r=0.343, r²=0.118), a weak correlation to relative peak isometric strength in IMTP (r=0.189, r²=0.036) and a strong correlation to peak anaerobic power, relative peak anaerobic power and the fatigue index in UWAnT (r=0.574, r²=0.329; r=0.769, r²=0.591; r=0.641, r²=0.411 respectively). In the thesis, the applied methods and the group of participants included are also discussed to find a suitable way of studying the relationship between these and other tests that could be suitable to explain different characteristics of boxing performance. Based on the findings in the thesis, it was concluded that HGS and IMTP do not explain strength in boxing performance and, therefore, should be studied further. Also, it was concluded that the different variables in UWAnT and CMJ do explain anaerobic power and capacity and lower body explosive strength in boxing performance and could, therefore, be used as sport-specific test for boxing.
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1. Background

Boxing is one of the oldest combat sports in history and one of the first sports to be introduced to the Olympic games and today, is widely practiced all over the world, where international boxing is governed by the International Boxing Association (AIBA) (Chaabène et al., 2014; AIBA, 2015). The physical level of boxers has increased during the last years, since training is more methodical and tools such as testing are used more. This may be because modern boxing to become more scientific. The aim of boxing is to hit the opponent without getting hit, which is the main criterion in scoring a bout (Chaabène et al., 2014). In competition, the winner is selected through scoring, technical knockout (TKO), knockout (KO) or walkover (WO). Scoring is done by five judges according to a ten-point-must-system, where the winner of each round is given ten points and the loser between six and nine points. A TKO decision is made after a boxer dominates the opponent so that he/she is not able to continue the bout. A KO decision is made after a boxer grounds the opponent who is not able to stand up to carry on within ten seconds (AIBA, 2015).

Boxers are divided into weight classes, ten for male boxers starting at 49 kg and 11 for female boxers starting at 46 kg (AIBA, 2015). The division of boxers into weight classes helps matchings between boxers on equal level, since boxers tend to be stronger relative to body weight compared to non-boxers at the same age (Chaabène et al., 2014). In Sweden, boxers are divided into weight categories as well as into level categories according to competitive experience in number of completed bouts; C-category (≤4 bouts), B-category (5-14 bouts) and A-category (≥15 bouts), which is based on the fact that boxers who have completed a higher number of bouts are at a higher level (Svenska Boxningsförbundet, 2016). Bouts are carried out, for male boxers, in three rounds of three minutes and, for female boxers, in four rounds of two minutes with one minute resting between rounds for both – a total of 11 minutes for both male and females (AIBA, 2015).

1.1. Physiological needs analysis

To investigate different tests’ relevance to boxing, an evaluation of the sport needs to be done by way of a needs analysis, which consists of an understanding of physiological terms that should explain the qualities that are emphasized by the sport. The components of boxing performance and the tests mentioned below have a physiological basis that can help understand their importance and their relationship to boxing performance. In this section, an explanation of the physiology of each component is provided.
1.1.1. Energy systems

The terms aerobic and anaerobic work refer to the three energy systems that dominate the energy production in the body (the production of adenosine triphosphate, ATP) during an activity and they depend on the presence and contribution of oxygen. Anaerobic work is where oxygen does not contribute to the production of ATP, and is dominated by the immediate and the short-term energy systems. In the immediate energy system, energy already exists in the body as stored ATP and phosphocreatine (PCr), where ATP is de-phosphorylated as it is used, and is re-phosphorylated with the help of PCr in a restating process. This energy system produces enough ATP to fuel maximal effort for around six seconds. In the short-term energy system ATP is produced at a fast rate through a process called glycolysis, during which glucose is metabolized. The glycolysis results in a small amount of ATP and lactic acid, but is a quick way to produce ATP at a high intensity. The aerobic work is where oxygen contributes to the production of ATP. This energy system is called the oxidative energy system as it is based on the oxidation of the source molecules (carbohydrates, fats and proteins). By oxidizing the carbohydrates, fats and proteins, a large amount of ATP is produced and a small amount of lactic acid remains, which enables long-term work on a low to medium intensity (McArdle, Katch & Katch, 2015).

The degree, to which the different energy systems dominate is described in figure 1. Depending on the intensity and duration of the work being done, and thereby the dominating energy system, lactate accumulates at different rates. There is an equilibrium between lactic acid formation and lactic acid clearance at light and moderate intensity, and the energy demands are met with the aerobic energy production. When the aerobic energy production does not meet the energy demands, the anaerobic energy systems start to dominate, which leads to a disruption in the equilibrium and lactic acid starts to accumulate, the point called the lactate threshold (McArdle et al., 2015).
The anaerobic capacity and the anaerobic fatigue index, the ones measured in this thesis, are factors that can describe an athlete’s level of anaerobic fitness, and thus the level to which the athlete can utilize the anaerobic energy systems and clear lactate from the blood. As in the upper body Wingate anaerobic test (UWAnT), a 30 second arm crank cycle ergometer test of all out work. In such a test, during the first five-second-interval of the test, the participants display their abilities to produce power using the immediate energy system. During the rest of the test, the participants display their abilities to keep producing power using the short-term energy system. Comparing the first and the last five-second intervals of the test shows the anaerobic fatigue index (McArdle et al., 2015). In boxing, this translates to the boxer’s ability to frequently attack and throw combinations at a high intensity, as well as the movement pattern carried out in a punching combination.

### 1.1.2. Strength and power

As earlier explained, the force produced in a boxing punch starts in the lower limb with a leg drive motion, which describes the need for strength in the lower limb in boxers (Loturco et al., 2015; Cheraghi et al., 2014). Strength is described as the ability to exert force, which depends on the load moved and the speed at which it is moved, and power is described as the rate at which force is exerted (Baechle & Earle, 2008). Trainable physiological factors that can affect strength are muscle cross-sectional area, the number of recruited motor units and the rate at which the motor units are fired. Muscle cross-sectional area is in proportion to the force that the muscle can produce, and this can be trained with hypertrophy training. During maximal strength training, the aim is to train the ability to recruit a large number of motor units, and during explosive training (power training), the aim is to...
increase the rate at which the motor units are fired (Baechle & Earle, 2008; McArdle et al., 2015).

In this thesis, both strength and power in the lower limbs were measured, as in isometric maximal strength and explosive strength (power). Muscle length (and thus joint angle) does not change during an isometric muscle action, and isometric strength is in proportion to muscle cross-sectional area (force exertion) (Baechle & Earle, 2008). Training isometric strength at a specific angle should result in strength gains at that angle, which is a limitation as the rest of the range of motion in the joint is ignored (McArdle et al., 2015). However, a number of papers have shown a strong relationship between isometric maximal strength and dynamic strength ($r=0.97$, $p<0.05$), suggesting that isometric maximal strength can be used as an indication of strength in athletes during testing (Beckham et al., 2013; Haff et al., 2016; McGuigan et al., 2010).

![Force-velocity curve](image.png)

**Figure 2** The force-velocity curve explaining the relationship between force and velocity, where maximal strength is carried out with high force and low velocity while speed occurs with low force and high velocity. Explosive strength, at peak power, is carried out with moderate, optimal force and relatively high velocity (Cardinale, Newton & Nosaka, 2011).

To measure explosive strength in the lower limbs, the ability to move a load at a high speed is measured. In a countermovement jump, the load is the participant’s body and the speed is put into a vertical movement to propel the participant upwards. Here, the lower limbs, hip-, knee- and ankle joints, are flexed before the jump. Here, a process called stretch-shortening cycle is utilized to help the participant create force. By flexing the lower limbs during the eccentric phase, the agonist muscles
are stretched and lengthened which results in a signalling from the central nervous system in a stretch reflex for the muscles to contract and shorten. By lengthening the muscles, elastic energy is also produced and stored in the tendons causing the muscle to recoil and shorten. Having a short amortization phase between the eccentric phase and the concentric phase, helps make use of the elastic energy and the spontaneous contraction created during the lengthening of the muscles. This is a process that is widely discussed in literature and many training methods, such as plyometric training and chock training, have been created based on it (Baechle & Earle, 2008; McArdle et al., 2015). Explosive strength in the lower limbs translates to using the lower limbs to drive force into punches and quickly moving and changing directions during a bout.

1.2. Some components of boxing performance

Boxing is a demanding sport, both mentally and physically and the physical aspects include strength, power, speed and endurance, both aerobic and anaerobic (Chaabène et al., 2014). To be able to choose the tests for this thesis, some of the important components of boxing performance will be discussed. A high level of cardiovascular fitness is considered important for boxers during rounds to withstand the metabolic demands of the work as well as between rounds for recovery, since a bout lasts 10-11 minutes (Chaabène et al., 2014). Guidetti, Musulin and Baldari (2002) showed that boxing performance is highly related to the anaerobic threshold and moderately related to maximum oxygen uptake ($\text{VO}_2\text{max}$). Multiple studies have showed a significant increase in both heart rate and blood-lactate concentrations in boxers during actual bouts, sparring and training (Khanna et al., 2006; Ghosh, Goswami & Ahuja, 1995). The high blood-lactate levels lead to the notion that boxers reach the lactate threshold early on in a bout, which makes training to improve anaerobic capacity and anaerobic power key in the development of boxers’ sport-specific fitness (Khanna & Manna, 2006; Guidetti et al., 2002; McArdle, 2015).

Another component is the strength and power production in both lower and upper limbs. In one study Loturco et al. (2015) showed strong to very strong correlations of strength and power measurements between upper and lower limbs in boxers. In another study, the activity of the joints in the lower limbs showed that they contribute to power production and speed in a punch with a leg drive motion (Cheraghi, Alinejad, Arshi & Shirzad, 2014). The lower limbs’ contribution to power production in a punch implies that strength and power training in the lower limbs is important for boxers (Cheraghi et al., 2014).

The contribution of the upper limbs to punching is also important. Guidetti et al. (2002) showed a strong relationship between boxing and hand grip strength and García, Harasymowicz, Viramontes, Órdenes and Vásquez (2010) showed that hand grip strength in boxers varies along with training.
periods. It is also widely suggested that boxers train strength in the upper limbs to help manage the punch force that is absorbed by the joints in the hand and arm during the contact phase of a punch (Whiting, Gregor & Finerman, 1988). Important to mention is that a boxing stance requires a boxer to have lead and rear hands and feet, which allows for a rotation to produce the largest amount of power possible. Here, boxers usually choose to place the dominant hand and foot as the rear hand and foot based on the notion that the dominant hand is the stronger one (AIBA, 2011).

1.3. Training time

Training volume describes the quantity of training planned for or completed by an athlete, and is one of the primary variables that athletes and coaches need to account for. The training volume could be defined in a number of ways depending on the sport, such as the total load in a strength session, the number of miles of running or the number of hours of sport-specific training. Considering the potential gains in strength-, endurance- and sport-specific training, it is well-established that athletes who are able to train more have a higher potential for improvement. However, for an optimal adaptation to training, the training volume needs equate recovery to minimize the risk for overtraining as well as take into account the training intensity (Bompa & Haff, 2009; Baechle & Earle, 2008). Quantifying combinations of training types could be difficult, so the time spent in training could be a variable that could give an impression of the amount of training completed – as in training time.

1.4. The tests

Based on the needs analysis discussed above, four tests were chosen – upper body Wingate anaerobic test (UWAnT) was chosen to measure the anaerobic capacity, isometric mid-thigh pull (IMTP) to measure maximal strength in the lower body, countermovement jump (CMJ) to measure explosive strength in the lower limbs and hand grip strength (HGS) to measure maximal strength in the upper limbs.

1.4.1. Upper body Wingate anaerobic test

Since anaerobic capacity and anaerobic power are important measures in monitoring boxing performance, a method for assessment of those features would be useful. The UWAnT is a test that evaluates a boxer’s anaerobic capacity and power in the upper body and is carried out on an upper body ergometer. It is described as a valid and reliable method for assessment of the desired measures (Lovell et al., 2012).

1.4.2. Isometric mid-thigh pull

Assessment of strength in the lower limbs could be accomplished through the measurement of the
isometric maximal strength (Beckham et al., 2013; Haff et al., 2016; McGuigan, Newton, Winchester & Nelson, 2010). Isometric maximal strength in the lower limbs is measured through an IMTP, where fixed bar at mid-thigh height is pulled and the force exerted in the pull is shown through a force plate. Peak isometric force (PIF) has shown a high correlation to sprint, power and agility performance according to Wang et al. (2016).

1.4.3. Countermovement jump
Assessment of power in the lower limbs could be accomplished through measurement of the jump height in a CMJ. This is a popular test due to its versatility, the little effort that subjects are exposed to and the little time it takes to perform. (Nuzzo, McBride, Cormie & McCaulley, 2008; Baechle & Earle, 2008).

1.4.4. Hand grip strength
The HGS test is commonly used to assess strength in the upper limbs, which was proved by multiple studies (Guidetti et al., 2002; García et al., 2010). Guidetti et al. (2014) showed that the HGS test in the dominant hand had a strong correlation to boxing performance. García et al. (2010) showed that HGS strength in boxers varied from one training period to another along with the performance level.

As mentioned earlier, training time could account for a higher fitness level and therefore could be used as an indication of that. In this thesis, the relationship between strength, power and anaerobic power and capacity measurements and training time was investigated using the abovementioned tests to establish if they are the right tools for the assessment of sport-specific fitness levels in boxing.

1.4.5. Training time
As for training time, the representative variable used was training time, which is the combined amount of time spent training during a week (hours/week). This was during the current competition period. By focusing on the total amount of strength-, endurance- and sport-specific training combined, the given training time could allow for an overview of the boxers’ training level. Since the given training time was during a competition period, a time at which boxers should be at a competitive level (Bompa & Haff, 2009; Mattsson, 2014).

2. Aim
The aim of this thesis was to determine the linear correlation between the weekly number of training hours during a competition period and each of the four different tests – upper body wingate anaerobic test, countermovement jump, hand grip strength and isometric mid-thigh pull – for 16 male boxers in the senior ranks.
The research questions were as follows:

- What is the linear correlation between the performance in upper body wingate anaerobic test and the weekly number of training hours for boxers in the senior ranks?

- What is the linear correlation between the performance in hand grip strength and the weekly number of training hours for boxers in the senior ranks?

- What is the linear correlation between the performance in countermovement jump and the weekly number of training hours for boxers in the senior ranks?

- What is the linear correlation between the performance in isometric mid-thigh pull and the weekly number of training hours for boxers in the senior ranks?

- Which of the four tests – upper body wingate anaerobic test, countermovement jump, hand grip strength and isometric mid-thigh pull – shows the strongest correlation to the weekly number of training hours in male boxers in the senior ranks?

3. Methods

3.1. Study design

The study design for this thesis was observational and cross-sectional. After the testing session, data was collected and analysed and a simple linear correlation between the between the weekly number of training hours and each of the test results was made. The collected data from the different tests was quantitative and the variable level was ratio (Norman & Steiner, 2014).

3.2. Participants

For this thesis, 16 male actively competing boxers (age=23±5 years) in the senior ranks (age span=18-40 years) were recruited from different boxing clubs in Sweden and included in the thesis. The exclusion criteria were injuries or illness that would have limited their performance in testing. All participants were given a document covering recommended preparation for the time leading up to the testing session. Recommendations included avoiding intake of big meals and any substances that can affect performance, such as caffeine and nicotine, two hours before the testing session, refraining from heavy training 48 hours before the testing session and wearing light training attire (Appendix 2) (Lovell et al., 2013).

3.3. Testing procedures and equipment

Apart from the physical testing, anthropometric measures (weight and height) of the participants were
measured to assure correct settings were put into the testing equipment, such as resistive load of ergometer in UWAnT and calculation of the relative values of the results (Lovell et al., 2013; Tanner & Gore, 2013). Testing of all participants was accomplished in one session, which included a warmup, anthropometric measurements, strength and power tests, a 20-minute resting period and UWAnT. Another test that participants did was a standing rotational power test which is included in a different thesis and was done together with the strength and power tests. In a previous study, HGS results showed a decrease after upper limb exercises, which are important for the setup and order of the tests during the testing session to ensure the highest possible performance in the participants (Grant, Robergs, Baird & Baker, 2014). Due to the large variation in body weight among the participants, a relative value was used for analysis in UWAnT and IMTP so that the results could be compared. The relative values were calculated by dividing the test results with the respective participants’ body weight (Tanner & Gore, 2013). Two testing sessions were completed, one in each of two locations, one in Halmstad, at Halmstad University, for the participants located in Halmstad and one in Malmö, at Malmö Sports Academy for the participants located in Malmö.

Before commencement of the testing session, participants were briefed about each test regarding the practical details. Before performing each test, each participant performed a familiarization run to try the given technique and during their performance, participants were verbally motivated to make an effort (Tanner & Gore, 2013). The anthropometric measures were done in the beginning of the test session followed by a warm-up, the strength and power tests, a 20-minute resting period and finally the UWAnT. At the end of the testing session, participants were instructed to cool down on an ordinary lower-limb cycle ergometer or jog for 5-10 minutes on a low intensity.

### 3.3.1. Training time

For the training time, as in the weekly number of training hours, participants were asked to recall the number of training hours completed the week before the testing session (Monday to Sunday), which was during a competition period. This included sport-specific-, strength and endurance training.

### 3.3.2. Height and weight

Measurements of height and weight were done before warm-up. To measure height, a Seca 213 portable stadiometer (Seca Deutschland, Hamburg, Germany) was used. Participants were instructed to stand with their feet together, touch the back of the platform with their heels and touch the stand with the buttocks, upper back and the back of the head. To measure weight, a scale Vågblock VB2-200-50 (VETEK, Vaddö, Sweden) was used. Participants were instructed to stand on the scale in their undergarments. Both weight and height were measured once and the measurements were rounded off
to one decimal.

3.3.3. Warm-up

The warm-up protocol included a five-minute general warm-up on a lower body ergometer or jogging on a running track, including four all out sprints of five seconds, followed by a five-minute specific warm-up for both the lower and upper limbs and five minutes’ dynamic stretching. The specific warm-up and the dynamic stretching used, were considered suitable and specific for the tasks that were anticipated during the testing session (Baechle & Earle, 2008).

3.3.4. Upper body Wingate anaerobic test

The UWAnT is a test that measures anaerobic capacity and power in an all-out maximum effort that lasts 30 seconds with a resistive load added equal to 5% of participant’s body weight (Lovell et al., 2013). UWAnT was performed on an arm crank cycle ergometer, Monark Cardio Rehab 891E (Monark Exercise AB, Vansbro, Sweden). During the UWAnT, participants were filmed using a GoPro Hero 5 (GoPro Inc., USA) to obtain the total number of pedal revolutions as well as for each five-second period (figure 3) (Lovell et al., 2013).

![Image of a GoPro camera](image)

**Figure 3** Obtaining the number of pedal revolutions using a GoPro camera.

Prior to the test, the height of the ergometer was adjusted to the height of the participant so that the arm crank was at the height of the participant’s chest. 5% of the participant’s body weight was calculated, taking away the weight of the loading basket on the ergometer, which weighs 100 grams (Lovell et al., 2013). After the load was added to the loading basket, the participants were instructed to tread as fast as possible for three seconds before the load was applied and then to keep treading as fast as possible for 30 seconds (Lovell et al., 2013). After obtaining the number of pedal revolutions
for each five-second period, peak anaerobic power output (WPP) was calculated for the first five second period, minimum power (WMP) was calculated for the last five-second period, anaerobic work was calculated as the average power (WAP) through the cumulative number of pedal revolutions for the 30-second test period, anaerobic fatigue index (WFI) was calculated through a comparison between the first and the last five-second periods and relative peak anaerobic power output (WRPP) was calculated by dividing WPP by the participant’s body weight. The formulas in figure 3 were used, where the number of pedal revolutions represents the distance travelled as every pedal revolution equals six meters travelled (McArdle et al., 2015; Bar-Or, 1987). WPP, WRPP and WFI were used for statistical analysis. The manual protocol is described by Gullstrand and Larsson (1999), Bar-Or (1987) and McArdle et al. (2015) as a valid protocol for obtaining peak anaerobic power, average anaerobic power and the fatigue index.

\[
\text{Peak power output (W)} = \frac{\text{PR for first 5s x Load(kp)x 6m/PR x 9,82 m/s}^2}{5s}
\]

\[
\text{Relative peak power output (W/kg)} = \frac{\text{Peak power (W)}}{\text{Body weight (kg)}}
\]

\[
\text{Average power (W)} = \frac{\text{Total PR for 30s x Load (kp)x 6 m/PR x 9,82 m/s}^2}{30s}
\]

\[
\text{Minimum power (W)} = \frac{\text{PR for last 5s x Load (kp)x 6 m/PR x 9,82 m/s}^2}{5s}
\]

\[
\text{Fatigue index (%) = \frac{\text{Peak power (W) - Minimum power (W)}}{\text{Peak power (W)}} \times 100}
\]

**Figure 4** Formulas used for the calculation of peak power (WPP), relative peak power (WRPP), average power (AvgP), minimum power (MinP) and the fatigue index (WFI) according to McArdle et al. (2015).

### 3.3.5. Isometric Mid-Thigh Pull

IMTP measures the isometric maximal strength (IMS), in which there is no change in joint angles or muscle length during the testing interval (Baechle & Earle, 2008). The test was performed on a MuscleLab portable force plate (Ergotest Innovation A.S., Porsgrunn, Norway) connected to a computer and placed in an adjustable rack with a fixed and adjustable bar (Beckham et al., 2013). The IMTP has shown a high correlation to strength and power measurements in the lower limbs, which, although it tests the IMS over the period that the athlete is standing on the force plate, the IMS relationship to dynamic power, in such as sprinting and jumping, has been shown to be strong (Wang et al., 2016; Beckham et al., 2013; Haff et al 2005). It is a well-known test among power athletes that has shown a high test-retest reliability and validity (Haff et al., 2005; Mcguigan et al., 2010).
The participants were instructed to stand on the force plate with the fixed bar at mid-thigh height and assume a position similar to the second pull in the clean, where the shoulders should be placed above the bar and the hands fixed to the bar with lifting straps to avoid grip stability affecting the performance (Beckham et al., 2013). No regard was given to the hip- and knee-angles since Comfort, Jones, McMahon and Newton (2015) showed that the peak force is not affected by the hip- and knee-angles as long as the bar was at the same height, midway between the iliac crest and the patella. This is important for the standardization since the bar needs to be adjusted to the right height for every participant. When ready, the participants were instructed to pull the bar as hard and as fast as possible and keep pulling for five seconds. Each participant performed the test three times with a one-minute resting period. Force was recorded on the computer. The average values of the three attempts was used as peak isometric force (PIF) and PIF was recalculated to relative peak isometric force (RPIF) by dividing it by the participant’s body weight. Both PIF and RPIF were used for data analysis.

### 3.3.6. Countermovement jump

The CMJ is a common test that measures jump height by recalculating the recorded time the participant spends in the air between the take off in the jump and the landing, which represents the lower limb power which the participant exerts to propel herself upwardly (Markovic, Dizdar, Jukic & Cardinale, 2004). Markovic et al. (2004) reported that CMJ is one of the most valid and reliable tests for measuring lower limb power after its comparison to other jump tests and that air-time based jump tests give a small measurement error. The test is performed on an IVAR IR-mat (LN Sport Konsult HB, Mora, Sweden) which consists of two units that create a mat of infrared light between them and the recording is based on the breaking of the light.

The participants were instructed to start with both feet parallel on the contact mat facing one of the units with the hands placed on the hips and then to flex the knees and hips to perform a downward movement followed by a jump as high as possible, extending the ankles, knees and hips. To avoid high stress on the knees, the participants were also instructed to land with a straight-leg rebound (a double-bounce) in the same place as the starting position (Markovic et al., 2004). The test was performed three times and the average of the three jump heights was recorded for data analysis.

### 3.3.7. Hand grip strength test

The HGS is a common test for measuring strength in the upper limb and one that has showed a good relationship to boxing performance, mostly explained by the determination that grip strength includes both arm and shoulder, which is a good indication of validity of the measurement in boxers (Guidetti et al., 2002). Gerodimos (2012) showed a high reliability of HGS test using a handheld dynamometer.
This test was performed using the digital hand grip strength dynamometer, T.K.K. 5401 Grip-D (Takei Scientific Instruments Co. LTD, Japan).

Participants were instructed to stand upright with both arms extended to the side and squeeze the dynamometer handle as hard as possible without bending their arms or legs (Guidetti et al., 2002). The test was performed three times for the dominant hand and an average of the three measurements was used in the data analysis.

### 3.4. Ethical and social considerations

Before testing, participants were informed of the approach of the thesis and the testing procedures and they read and signed an informed consent document containing all information needed including benefits, risks, their right to choose if they want to participate and their right to end their participation at any time with no questions asked (Appendix 1). This was done according to the Declaration of Helsinki (Laake, Benestad & Olsen, 2007). Also, participants were informed that they were not covered by any insurance during their participation in the study and that they were to make use of their personal insurance in case of injury during the tests.

The social gain of this thesis is within the sport of boxing, where there is a need for systematic ways for testing boxers’ fitness levels. A number of factors need to be considered before a testing session and these include the suitability and validity of the chosen tests (Tanner & Gore, 2013), a. By studying the relationship to boxers’ training time, this thesis could assess the suitability of HGS, CMJ, IMTP and UWAnT for boxing and could be a starting point of assembling a testing battery that is suitable for boxing. This way, a systematic way of testing boxers could be created to help boxing trainers in evaluating boxers’ fitness levels in monitoring their fitness levels.

### 3.5. Data collection and statistical analysis

Data collection and statistical analysis were done in SPSS 20.0 (IBM Corp, 2011, Version 20.0. Armonk, New York, USA). A Shapiro-Wilk test of normality, with the significance level set to p>0.05, showed a normal distribution for all variables except CMJ, therefore, parametric statistical analysis was done using Pearson correlation for all variables (Norman & Steiner, 2014; Pallant, 2010). The level of significance for the correlation, which determines the level at which the correlations were found by chance, was set to p=0.05. The limits that determine the strength of the relationship between the variables were set to 0.00-0.29 for weak, 0.30-0.49 for moderate, 0.50-0.79 for strong and 0.80-1.00 for very strong (Pallant, 2010). To determine the shared variance between the number of weekly training hours and the results in each of the tests, the level to which the weekly number of training hours explain test results, the coefficient of determination (r²) was also calculated.
For the strength and power tests, the results suggested that the number of weekly training hours has a positive weak relationship to HGS \((r=0.236, r^2=0.056)\), a positive strong relationship to CMJ \((r=0.570, r^2=0.325)\) and a positive weak relationship to both PIF \((r=0.343, r^2=0.118)\) and RPIF \((r=0.189, r^2=0.036)\). As for the UWAnT, the results suggested that the number of weekly training hours has a strong relationship to WPP \((r=0.574, r^2=0.329)\), WRPP \((r=0.769, r^2=0.591)\) and WFI \((r=0.641, r^2=0.411)\). Based on the correlations, the test with the strongest correlation to the weekly number of training hours was UWAnT. The results are presented in table 1 as mean, standard deviation (SD), correlation coefficient (r), level of significance (p) and coefficient of determination \(r^2\).

**Table 1** Mead, standard deviation (SD), correlation coefficient (r), level of significance (p) and coefficient of determination \(r^2\) for each of the tests – HGS, CMJ, PIF, RPIF, WPP, WRPP and WFI.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>Pearson correlation (r) for Number of weekly training hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of weekly training hours (h)</td>
<td>11.50 (3.25)</td>
<td>(r=0.0)</td>
</tr>
<tr>
<td>HGS (kg)</td>
<td>53.39 (9.20)</td>
<td>(r=0.236) (p=0.378, (r^2=0.056))</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>35.63 (4.02)</td>
<td>(r=0.570) (p=0.021, (r^2=0.325))</td>
</tr>
<tr>
<td>PIF (N)</td>
<td>3068.89 (578.05)</td>
<td>(r=0.343) (p=0.193, (r^2=0.118))</td>
</tr>
<tr>
<td>RPIF (N/kg)</td>
<td>40.38 (4.44)</td>
<td>(r=0.189) (p=0.483, (r^2=0.036))</td>
</tr>
<tr>
<td>WPP (W)</td>
<td>600.24 (134.05)</td>
<td>(r=0.574) (p=0.020, (r^2=0.329))</td>
</tr>
<tr>
<td>WRPP (W/kg)</td>
<td>7.85 (0.97)</td>
<td>(r=0.769) (p=0.001, (r^2=0.591))</td>
</tr>
<tr>
<td>WFI (%)</td>
<td>39.97 (15.01)</td>
<td>(r=0.641) (p=0.007, (r^2=0.411))</td>
</tr>
</tbody>
</table>
Figure 5 Scatter plots showing the linear correlations of A) HGS ($r=0.236$; $r^2=0.056$), B) CMJ ($r=0.570$; $r^2=0.325$), C) PIF ($r=0.343$; $r^2=0.118$), D) RPIF ($r=0.189$; $r^2=0.036$), E) WPP ($r=0.574$; $r^2=0.329$), F) WRPP ($r=0.769$; $r^2=0.591$) and G) WFI ($r=0.641$; $r^2=0.411$) respectively to training time ($n=16$).
5. Discussion

5.1. Results

The main results of this thesis show weak to moderate correlations between training time and both strength tests HGS and IMTP as well as strong correlations in the power test CMJ and the anaerobic capacity test UWAnT. UWAnT was also the test that showed the highest correlations to training time.

The weak to moderate correlations for the HGS and IMTP (PIF and RPIF) imply that these tests do not fully explain strength in boxing performance, neither in the upper body, nor in the lower body. In contrast to these results, Guidetti et al. (2002) has shown that HGS has a strong relationship to the ranking of internationally ranked Italian boxers in the same weight category (81 kg), which is a homogenous group. Also, Garcia et al. (2010) showed that results in HGS, in a group of elite Mexican boxers, changed over the season where the highest results were obtained during the competition period. Beckham et al. (2013), Haff et al. (2016) and McGuigan et al. (2010) have shown that IMTP measures isometric maximal strength in the lower limbs with high reliability, which as earlier mentioned, is an important component in boxing. Loturco et al. (2016) found strong correlations (0.68-0.83) between power measurements in different punches and isometric maximal strength in the lower body in a half-squat in elite Brazilian boxers. The findings in this thesis regarding HGS and IMTP somewhat contradict the findings in earlier research, which could be owing to possible errors in the standardization or the study design, which used training time to rank the participants.

The strong correlations between training time and UWAnT (WPP, WRPP, WFI) in this thesis imply that UWAnT could explain anaerobic power and capacity in boxing performance, specifically in the upper body, which is in conjunction with earlier research (Hübner-Wozniak, Kosmol & Blachino, 2011; Lovell et al., 2012; Svenska boxningsförbundet, 2011). Hübner-Wozniak et al. (2011) used UWAnT to compare anaerobic capacities in elite boxers and wrestlers and found that athletes in both sports exhibited similar and high blood lactate levels, although wrestlers showed a higher power output than boxers. Ghosh et al. (2010) found that blood lactate levels in boxers reached 14.5±0.6 mmol/L after a simulated bout and Hübner-Wozniak et al. (2011) found almost similar blood lactate levels after UWAnT (12.3±2.4 mmol/L).

The strong correlation between training time and CMJ implies that this test could explain lower body explosive strength in boxing performance. This agrees with earlier research. Loturco et al. (2016) found strong correlations (0.67-0.80) between power measurements in different punches and the countermovement jump in a group of Brazilian boxers.
5.2. Methods

The method that was used in this thesis was focused on the correlation of training time in the form of weekly number of training hours in boxers. Training time is, however, not a training variable that alone allows for improvements in athletes’ fitness levels due to the factors including progression, load and intensity, individual physiological potential, type of training, the ratio between strength-, endurance- and sport-specific training and the amount of recovery between sessions (Bompa & Haff, 2009; Mattsson, 2014; Kraemer & Ratamess, 2003). Also, the method of quantification of training time used in this thesis is non-systematic and has no scientific evidence for its reliability. Other methods of data collection, such as training diaries and questionnaires that have been scientifically evaluated, could also have flaws and questionable reliability but could help in obtaining more reliable results than training time.

UWAnT was performed on an arm crank cycle ergometer model which is usually used for rehabilitation training. It does not connect to a computer, nor does it display the desired variables such as peak power output. Therefore, the variables were manually calculated by filming the participants during their performance to manually count PR for a recalculation, which is, as previously mentioned, a reliable and valid protocol. However, for the sake of the simplicity in testing and accuracy in the recalculation of results, obtaining the desired variables automatically would be preferred. The protocols used for CMJ, HGS and IMTP followed the ones used in earlier research and were all described as valid and reliable. This implies that the testing procedures and the implementation of the testing protocols could not have affected the results differently from previous studies (Lovell et al., 2012; Beckham et al., 2013; McGuigan et al., 2010; Wang et al., 2016; Nuzzo et al., 2008; Guidetti et al., 2002).

A possible factor that could have affected the standardization is that testing was completed on two different locations, as the environment in the two locations may have been different. 5 boxers were tested in Malmö and 11 boxers were tested in Halmstad. As for the difference in equipment, IMTP was the only test that used two different force plates and bars, which could have had an effect on the standardization of the test due to the possible change of grip stability of the bar and the calibration of the force plate. This is, however, not a crucial change, since the force plate and software were of the same brand and model. As for the environmental factor, testing was completed in controlled physiological laboratories with the same testing staff, which might or might not have had an influence on test results (Tanner & Gore, 2013).
Participants included in this thesis were actively competing male boxers in the senior ranks with no regard to weight division, level of competition or training background. This results in a heterogenous group of participants with mixed unknown factors and bias, such as physical and physiological attributes, level of competition and boxing experience as well as training background. The weak correlations observed may be due to a diversity between the participants with respect to body type and dominant muscle fibre type, in which some have higher potential for strength gains than others, meaning that they have a higher percentage of type-II muscle fibres. This is discussed as the tests used in this thesis measure strength, power and anaerobic capacity and power, where the type-II muscle fibres are favoured (McArdle et al., 2015). Another aspect of diversity that could have had an influence on the participants’ performance is their training background, in which some of the participants may have had a better foundations of strength training on account for long backgrounds in strength training and engagement in other sports for long periods of time (Bompa & Haff, 2009; Baechle & Earle, 2008). To further investigate the diversity among the participants, the means and standard deviations (table 1) could also be used, in which the standard deviation describes the spread of the results among the participants and the percent deviation describes the same spread but in percent (Norman & Steiner, 2014).

To avoid bias, a way future research could determine the chosen tests’ relevance to boxing could be to use specific attributes for the analysis instead of a non-specific variable like training time, such as measured punching power or speed (Loturco et al., 2015). Measured punching force have shown to increase with the competitive level of boxers, which implies that future studies could use competitive ranking or level to determine different tests’ suitability for the sport. This way, including a homogenous group of boxers and systematically ranking them according to their national or international competitive ranking (Guidetti et al., 2002) may be an applicable way of designing such studies. Training time was used in this thesis due to the number of boxers available in the region, which is a small number and a limit to grouping. Their competitive levels varied, which also limited the use of a national or international ranking. If a larger group of boxers would be available for a future study, a comparison between boxers at different levels, as in novice and elite could be possible. Another way to compare groups would be of a group of boxers and a group of non-boxers, which would make the non-boxer group a control group. This type of study design could show clear differences between the groups and the level bias may be reduced (Pallarès, López-Gullón, Muriel, Díaz & Izquierdo, 2011).

As described in the background, explosive power in the lower limbs and maximal strength in the upper limbs contribute directly to punching power in boxing. Suggestions for future research
questions derived from this thesis: What is the linear correlation between measured punching force and isometric mid-thigh pull, hand grip strength and countermovement jump respectively? Is there a difference between novice and elite boxers in isometric mid-thigh pull, hand grip strength and countermovement jump respectively?

6. Conclusions

Based on the findings of this thesis, it could be concluded that CMJ and the different variables in UWAnT, as in WPP, WRPP and WFI, have a strong relationship to boxing performance and training and CMJ and UWAnT could be useful tests for testing and monitoring boxers’ fitness level. Furthermore, HGS and IMTP do not explain an ample part of boxing performance, however, due to the heterogeneity of the data and the conflict of the results with earlier research, the relationships between HGS and IMTP and boxing performance need to be analysed further.
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8. Appendix 1 – Informed consent (Swedish)


Deltagande innebär ett testtillfälle där de fyra testerna kommer att genomföras. Testtillfället börjar med styrke- och power-tester; ett hopptest med hjälp av en IR-matta för explosivitet i underkroppen, ett isometriskt styrketest för maximal styrka i underkropp, handgreppsstyrka i båda händerna med hjälp av en handdynamometer för styrka i hand, arm och axel samt ett stående rotationstest för maximal styrka och explosivitet i rotation, vilka genomförs i maskinen 1080 Quantum.

Efter styrke- och power-testerna följer en vila på 20 minuter uppföljd av ett max test, Wingate anaerobt test, som varar 30 sekunder och genomförs i en armcykel för att ge värden på anaerob kapacitet i överkroppen. Samtliga tester är maxtester men är måttligt ansträngande att genomföra för en träningsvan person. Vid testtillfället kommer även antal genomförda matcher att noteras för att en jämförelse mellan boxares nivå och resultat från fystesterna kan genomföras och längd och vikt kommer att mätas hos deltagare.

Testerna kommer att genomföras noggrant med ständig närvarande testledare och säkerhet för testdeltagare prioriteras för att minimera skaderisken. Testerna kommer äga rum i N-huset på Högskolan i Halmstad. Testerna beräknas att sammanlagt att ta ca 1-2 timmar att utföra.

För att delta i studien ska du vara på seniornivå (mellan 18-40år) samt aktivt tävlande inom boxning. Vid testtillfället ska du vara fri från skada eller sjukdom i kroppen för att deltaga och om sjukdom eller skada uppstår innan testtillfället bör du säga till testledare.

Deltagande i studien är helt frivilligt och du har befogenhet att när som helst under studiens gång avbryta din medverkan utan att behöva förklara varför. Samtliga uppgifter som samlas in under studien förvaras konfidentiellt. Dina personuppgifter och ditt deltagande framkommer inte i projektet. Studiens resultat såväl som dina egna resultat kommer du som deltagare att få ta del av.
Jag godkänner att information om mig och mina testresultat hanteras av testledare.

Jag bekräftar att jag valfritt deltar i studien och har kännedom om att jag kan hoppa av studien när jag vill utan att frågor ställs.

Jag har tagit del av information om vad jag deltar i studien med och vilka risker som finns.

Jag har tagit del av information om vad studiens syfte är och nytan av dess genomförande.

Jag har tagit del av ovanstående information och ger mitt samtycke att delta i studien.

_________________________________________________
Namnförttydligande

_________________________________________________
Underskrift, Ort och Datum

Är du under 18 år krävs målsmans namnteckning.

_________________________________________________
Målsmans namnförttydligande

_________________________________________________
Målsmans underskrift, Ort och Datum

För frågor eller mer information om studien, testerna eller resultat är du välkommen att kontakta någon av nedanstående via telefon eller mejl:

Mohammed Khudair, Testledare  
mo.frss@gmail.com

Mikael Dabrowski, Testledare  
Powski90@gmail.com

Eva Strandell, Handledare  
Eva.strandell@hh.se
9. Appendix 2 – information to participants (Swedish)

9.1. Riktlinjer inför tester

- Undvik hårdare träning 48 timmar innan testet.
- Välj lättare träning om du ska träna dagen för testerna.
- Undvik att äta två timmar innan testerna.
- Avstå från koffeinhaltiga livsmedel, läkemedel och kosttillskott.
- Avstå från att röka eller snusa timmarna innan testet.
- Var ombytt till lättare träningskläder och träningsskor inför testerna och ta med dig en vattenflaska.
- Du får göra uppvärmning på plats, dvs du behöver inte värma upp innan testerna.

9.2. Under tester


9.3. Handstyrka


9.4. Countermovement jump

9.5. **Stående rotationstest**


9.6. **Isometrisk maxstyrka i underkroppen**

I detta test mäts maximal isometrisk styrka i underkroppen genom att dra i en fixerad stång stående på en kraftplatta. Draget liknar det andra draget i en frivändning eller ett marklyft där stången är fixerad i höjd med mitten av låren. Då stången inte kommer att flyttas och vinklarna i droppen är konstanta blir rörelsen isometrisk. Här kommer stången att justeras innan testet och du kommer att få kalk (flytande magnesium) att ha på händerna för att stärka ditt grepp om stången. Du ska vara rak i ryggen och dra så hårt du kan genom att pressa ner fötterna i kraftplattan. Du drar i fem sekunder och testet genomförs tre gånger.

9.7. **Wingate anaerobt test för överkroppen**


9.8. **Efter tester**

Efter testerna kommer du att kunna ta del av dina testresultat. Resultat kommer att sammanfattas för att söka en koppling av dessa tester till boxning, vilket innebär att de kan användas för att testa boxares fysiska nivå.
10. Appendix 5 – Calculations

The following calculations are an example in the Upper body Wingate anaerobic test, an example for how calculations were carried out to find peak power, relative peak power and fatigue index according to the formulas given by Mcardle, Katch and Katch (2015).

\[ \text{Peak power output (W)} = \frac{13 \times 3.3 \text{ kg} \times 6 \text{ m/PR} \times 9.82 \text{ m/s}^2}{5 \text{ s}} = 505.52 \text{ W} \]

\[ \text{Relative peak power output (W/kg)} = \frac{505.52 \text{ W}}{64.6 \text{ kg}} = 7.82 \text{ W/kg} \]

\[ \text{Average power (W)} = \frac{63 \times 3.3 \times 6 \text{ m/PR} \times 9.82 \text{ m/s}^2}{30 \text{ s}} = 408.32 \text{ W} \]

\[ \text{Minimum power (W)} = \frac{8 \times 3.3 \times 6 \text{ m/PR} \times 9.82 \text{ m/s}^2}{5 \text{ s}} = 311.10 \text{ W} \]

\[ \text{Fatigue index (%) = } \frac{505.52 \text{ W} - 311.10 \text{ W}}{505.52 \text{ W}} \times 100 = 38.46 \% \]
11. Appendix 6 - Equipment

Seca 213 portable stadiometer (Seca Deutschland, Hamburg, Germany)
Vågblock VB2-200-50 (VETEK, Vaddö, Sweden)
Monark Cardio Rehab 891E (Monark Exercise AB, Vansbro, Sweden).
GoPro Hero 5 (GoPro Inc., USA)
MuscleLab portable force plate (Ergotest Innovation A.S., Porsgrunn, Norway)
IVAR IR-mat (LN Sport Konsult HB, Mora, Sweden)
T.K.K. 5401 Grip-D (Takei Scientific Instruments Co. LTD, Japan)
Computer with MuscleLab Professional software (Ergotest Innovation A.S., Porsgrunn, Norway)
Adhesive tape
Tape measure
Liquid chalk
Pulling straps
Computer with SPSS 20.0 (SPSS INC, USA)
Tank you!