BACHELOR THESIS

Validation study of a portable accelerometer to measure muscular power output

Correlation between the Beast Sensor and the linear encoder MuscleLab

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Abstract

Background: The ability to produce a high power output can be the deciding factor in determining which athlete wins or loses in a sporting event. Power output can be measured in an exercise like the squat or bench press. The use of a force plate, or a force plate paired with a linear position transducer is considered the gold standard when measuring power output in an exercise like the squat or bench press. Linear position transducers or linear encoders have also been considered valid methods. Power output can also be measured by accelerometers.

Purpose: The purpose of this study was to test the concurrent validity of the accelerometer Beast Sensor by measuring average power in explosive squatting and bench pressing at 40 % and 80 % of one repetition maximum (1RM). The linear encoder MuscleLab was used as criterion.

Methods: 17 test subjects, five women and 12 men (average age 28 years) were recruited. Fifteen of the subjects completed two test sessions. The first session determined their 1RM. The second session took place 7-14 days later and measured average power output during two sets of three repetitions at 40 % and 80 % of the subjects 1RM in explosive squats and bench presses. The average power output of the repetitions was measured simultaneously by Beast Sensor and MuscleLab. For the Beast Sensor to be considered valid, a correlation coefficient of 0.9 or higher needed to be reached.

Results: Beast Sensor demonstrated high or very high correlations with MuscleLab for average power output of explosive squats at 40 % of 1RM ($r_s = 0.91$), and for explosive bench presses at 40 % ($r_s = 0.86$) and 80 % of 1RM ($r_s = 0.74$). However, for explosive squats at 80 % of 1RM, the correlation was low ($r_s = 0.42$). All correlations were statistically significant with p-values of < 0.01. Beast Sensor was considered valid for squats at 40 % of 1RM, but neither at 80 % of 1RM in squats, nor at 40 % or 80 % of 1RM in bench presses.

Conclusion: Beast Sensor showed high or very high correlations with the criterion MuscleLab in three of the four assessed data variables. Only the correlation for average power output of the explosive squats at 40 % of the subject's 1RM reached the required correlation coefficient of 0.9 or higher for the Beast Sensor to be considered valid. Except for at 40 % of 1RM in squats, Beast Sensor missed a substantial amount of repetitions. Further studies examining the reliability of the Beast Sensor are therefore needed.

Abstrakt

Bakgrund: Förmågan att producera hög effektutveckling (power) kan avgöra vilken idrottare som vinner eller förlorar en tävling. Effektutveckling kan mätas i övningar som knäböj och bänkpress. Detta kan göras med hjälp av en kraftplatta, eller en kraftplatta parad med en linear position transducer. Dessa metoder anses vara "gold standard", men linear position transducers eller linear encoders har också ansetts vara valida metoder. Effektutveckling kan även mätas med hjälp av en accelerometer.

Syfte: Syftet med denna studie var att mäta samtidig validitet hos accelerometern Beast Sensor genom att mäta genomsnittlig effektutveckling i explosiva knäböj och bänkpressar vid 40 % och 80 % av en repetition max (1RM). MuscleLab, en linear encoder, användes som referensvärde.

Metod: 17 försökspersoner, fem kvinnor och tolv män (medelålder 28 år) rekryterades. Femton av försökspersonerna fullföljde deltagande. Vid det första testtillfället mättes 1RM. Det andra tillfället ägde rum 7-14 dagar senare och mätte genomsnittlig effektutveckling i explosiva knäböj och bänkpressar vid 40 % och 80 % av försökspersonernas uppmätta 1RM. Två set av tre repetitioner mättes vid 40 % och 80 % av 1RM i både knäböj och bänkpress. Repetitionerna mättes samtidigt av MuscleLab och Beast Sensor. För att Beast Sensor skulle anses vara valid behövde en korrelationskoefficient på 0.9 eller högre uppnås.

Resultat: Beast Sensor uppvisade höga eller väldigt höga korrelationer med MuscleLab för genomsnittlig effektutveckling i explosiva knäböj vid 40 % av 1RM ($r_s = 0.91$) och explosiva bänkpressar vid 40 % ($r_s = 0.86$) och 80 % av 1RM ($r_s = 0.74$). Dock uppmättes en låg korrelation för de explosiva knäböjen vid 80 % av 1RM ($r_s = 0.42$). Alla korrelationer var statistiskt signifikanta med p-värden på < 0.01. Beast Sensor ansågs vara valid för att mäta effektutveckling vid 40 % av 1RM i knäböj, men varken vid 80 % av 1RM i knäböj, eller vid 40 % eller 80 % av 1RM i bänkpressar.

Slutsats: Beast Sensor visade höga eller väldigt höga korrelationer med referensvärdet från MuscleLab för tre av de fyra uppmätta variablerna. Endast korrelationen för genomsnittlig effektutveckling i explosiva knäböj vid 40 % av 1RM uppnådde den korrelationskoefficient på 0.9 eller högre som krävdes för att Beast Sensor skulle anses vara valid. Förutom vid 40 % av 1RM i knäböj, missade Beast Sensor en väsentlig andel repetitioner. Därför finns det ett behov av fler studier som undersöker reliabiliteten hos Beast Sensor.

Table of contents

Background

Power

The ability to produce a high power output is crucial to athletes in many different sports. The amount of power an athlete generates in a power test depends on various factors, such as range of motion in the involved joints, as well as which muscle groups are involved. Different types of movements, for example concentric or eccentric, will also affect power output (Harman, Rosenstein, Frykman, Rosenstein & Kraemer, 1991). The power output an athlete can generate is thought to be the most important factor in deciding who wins or loses during sporting events (Cardinale, Newton & Nosaka, 2011). Being able to measure power during training and testing of athletes is a valuable tool in many sports. There are several different types of tests to measure power, including using an instrument like a force plate or a linear encoder while performing an exercise like the squat or bench press.

The origin of the use of the term power goes back to work done on steam engines by James Watt (1736-1819). The steam engines were meant to replace horses when higher industrial demands arose in the 1700s. James Watt is said to be the first to use the term "horsepower" to compare the output of an engine to that of a horse. In Watt's work, one horsepower is equal to 745.7 Watt (W) (Winter & Fowler, 2009). Watt has thus given his name to the unit in which power is measured. Power can be defined as "the rate at which mechanical work is done" (Winter & Fowler, 2009, p. 453). When lifting a barbell a certain distance, power output will differ depending on the speed with which the barbell is lifted (Grimshaw, 2006).

Power can be described as the product of force and velocity: *power = force x velocity (P=Fv)*. The first part of the equation: Force is the product of mass and acceleration and is measured in Newtons (N). Mass is measured in kilograms, and acceleration is measured in meters per second squared (m/s^2). The second part of the power equation is velocity and velocity is measured in meters per second (m/s).

Power can also be calculated by dividing the amount of mechanical work done by the time the work takes: *power = work/time (P=W/t)*. Work is defined as force times displacement: *work = force x displacement (W=Fd)* (Noffal & Lynn, 2012). Work is measured in joule (J) or kilojoule (kJ) (Winter & Fowler, 2009). Equations for power can be seen in table 1. It should be noted that when assessing power output in the squat or bench press, it is the displacement

in the vertical plane that is being measured. When movement occurs through a joint, leading to an angular displacement, power can instead be defined as: *power = torque x angular velocity* (Noffal & Lynn, 2012).

Table 1. Definitions for force, work and power with their respective equations and The International System of Units.

Definitions	Equation	Unit
Force	F=ma	Newtons (N)
Force	F=mg	Newtons (N)
Work	W=Fd	Joule (J)
Power	P=Fv	Watt (W)
Power	P=W/t	Watt (W)

Definitions: m = mass, a = acceleration, g = gravity, d = displacement, v = velocity, W = work, t = time.

Average power can be calculated over a complete range of motion in an exercise, while peak power is the highest output of power that can be found at any specific part of the movement. For endurance events, average power output correlates with performance. For more explosive activities like sprinting and jumping, peak power is a crucial component of success (Cardinale, Newton & Nosaka, 2011).

This thesis will use two devices to measure average power output: Beast Sensor (Beast Technologies, Brescia, Italy), which uses the equation P=Fv to calculate average power output (Peter, Beast Team, personal communication, March 29, 2017), and MuscleLab (MuscleLab 4010, Ergotest Innovation, Langensund, Norway), which also uses P=Fv to determine average power output (Hilmersson, Edvardsson & Tornberg, 2015).

Importance of power to an athlete

An athlete's ability to produce a high power output is a central component of success in most sports. Activities such as jumping, sprinting, and being able to quickly change direction are all dependent on the amount of power the athlete can generate (Haff & Nimphius, 2012). Power output also determines an athlete's ability to accelerate in most sports, for example football or basketball (Newton & Kraemer, 1994).

Several studies have shown that when athletes of a higher division in a sporting league are compared to athletes of a lower league, the higher league athletes were capable of producing a higher power output. Power output capabilities were also higher for athlete's starting matches

for their teams than athlete's sitting on the bench. Additionally, peak power output significantly correlates with performance on the agility based T test (Haff & Nimphius, 2012).

It has been stated that it is necessary to improve maximum strength to improve power output (Bompa & Buzzichelli, 2015). However, even if a training period does not improve an athlete's one repetition maximum (1RM), there could still be an improvement in the capability to produce high velocity at various loads of a movement. An argument can be made for training with lower loads and higher velocities instead of focusing too much on increasing maximum strength (Harris, Cronin, Taylor, Boris & Sheppard, 2010). A linear position transducer can help identify at which percentage of 1RM in a specific exercise an athlete produces the highest power output. This makes it possible to examine what effect a training intervention has on power output (Harris, Cronin, Taylor, Boris & Sheppard, 2010).

To determine where an athlete produces the highest amount of power in a specific exercise, the athlete's power output can be measured at a certain external load. The exercise is then performed repeatedly, with the added weight being increased or decreased through a range of loads. Due to the force/velocity relationship, this will affect power output. (Cardinale, Newton & Nosaka, 2011).

When the goal is to increase power output, the load at which the athlete reaches the highest amount of power is considered the optimal load (Cardinale, Newton & Nosaka, 2011). To most effectively increase power output, an athlete needs to train with a resistance that gives the highest power output possible through a high velocity of the movement (Kawamori & Haff, 2004). Haff and Nimphius (2012) add that there are three main considerations to increase power output: First, muscular strength needs to be maximized. Secondly, the ability to rapidly create high forces should be improved. Thirdly, when the velocity of a muscle contraction increases, the athlete still needs to be able to improve ability to create a high amount of force (Haff & Nimphius, 2012).

When it comes to maximizing power output, a mixed method needs to be used. A lower load will most likely affect the higher velocities generated, while a higher load might have a bigger effect on the higher force portion of the force-velocity curve. A mixed method could be applied by including jump squat with a low load, as well as heavier squats. This would target a wide range of the force velocity curve (Haff & Nimphius, 2012). The force-velocity curve is based on the fact that the higher the muscular force generated is, the slower the muscle will shorten, and vice versa. Performing a one repetition maximum will create the maximum force

possible, but the contraction will be slow which will result in a low power output. Maximal power on the other hand, will be produced when lifting moderate loads (Baechle & Earle, 2008).

Muscular contraction

A sarcomere is the basic contractile unit of skeletal muscle. Before a muscle can contract, its muscle fibers need a stimulus from the nervous system. This occurs at the neuromuscular junction, where an action potential releases a neurotransmitter called acetylcholine. The acetylcholine binds to receptors on the muscle fiber, which starts an action potential along its sarcolemma. When the action potential reaches the sarcoplasmic reticulum, stored calcium will be released. The calcium will move through the sarcoplasm so that it can bind to troponin molecules that can be found along the actin filaments. Once the calcium is bound to troponin, the troponin will change its shape which leads to tropomyosin moving, opening up binding sites on actin where a myosin head can attach (Coburn & Malek, 2012).

Once the binding sites on actin are open, the myosin head can use its stored energy from the breakdown of adenosine triphosphate (ATP) to adenosine diphosphate and inorganic phosphate to form a cross-bridge with the actin. The myosin head can then try to move the actin filament toward the center of the sarcomere. Movement will only be achieved if the force the myosin heads can generate is higher than the external force going the other way (Coburn & Malek, 2012).

After potentially moving the actin filament, the myosin head needs an addition of new ATP to be able to detach from the actin filament. When the ATP binds to the myosin head and it is released from the actin filament, the enzyme adenosine triphosphatase splits the ATP, once again leaving the myosin head energized. As long as the binding sites on actin are open, the myosin head has a possibility to form another cross-bridge with actin to keep trying to move it toward the center of the sarcomere. This will continue as long as motor neuron stimulates the muscle fiber to contract (Coburn & Malek, 2012).

Validity

When discussing empirical measurements, a distinction can be made between reliability and validity. Reliability concerns repeated tests, where a high reliability indicates that the measurement of the repeated test ends up with the same result (Carmines & Zeller, 1979). A basic description of validity is that "in a very general sense, any measuring device is valid if it

does what it is intended to do" (Carmines & Zeller, 1979, p. 12). Distinctions between different types of validity can be made. Some examples are content validity, construct validity and criterion-related validity, where the criterion validity can be further divided into concurrent and predictive validity (Carmines & Zeller, 1979).

Concurrent validity is tested when the measurement equipment being validated is used simultaneously with the criterion. Predictive validity describes how well a target test can predict the results of the criterion test (Portney & Watkins 2009). Validity can also be relative or absolute. A strong correlation between two test instruments yield relative validity, but the mean values can still differ from the criterion test. This affects the absolute validity of the tested instrument (Crewther et al, 2011). In this thesis, Beast Sensor was tested for concurrent validity, using MuscleLab as the criterion.

Gold standard

For some of the power tests, a force plate can be used. This technique is considered the "gold standard" when it comes to testing strength and power. An issue with the force platform is that it is expensive and most often found in a scientific setting, such as a laboratory (Garnacho-Castaño, López-Lastra, Maté-Muñoz, 2015). However, it has also been stated that a force platform should be combined with a linear transducer to be considered the gold standard for assessing performance measures such as power (Nigg & Herzog 2007).

If there is a scientific consensus on what's the best available test for any given situation, this test may be used as a gold standard. The test can then be used as a reference for other tests to be compared to, but this doesn't mean it should be considered perfect (Versi, 1992). The phrase gold standard was originally an economical term for a monetary standard and was never meant to equal perfection (Classen, 2005). Additionally, Versi (1992) points out that the gold standards are always challenged. Once enough data has been compiled to conclude that a test no longer is the best one available, a newer test can take the place of gold standard.

Measuring power output

Even though either a force plate, or a force plate paired with a linear position transducer has been referred to as gold standard in the scientific literature, other types of test instruments have been used as a criterion when validating a new test instrument. For example, a three-dimensional video analysis system has been deemed valid and reliable enough to be used as a criterion when measuring kinematics such as movement velocity (Sato, Beckham, Carroll,

Bazyler & Sha, 2015; Busca & Font, 2011). Video recordings was also used as a criterion for validating a linear position transducer (Drinkwater, Galna, McKenna, Hunt & Pyne, 2007)

A linear velocity transducer has been used to validate the linear position transducer Tendo Weightlifting Analyser System (Garnacho-Castaño, López-Lastra and Maté-Muñoz, 2015). Finally, a linear position transducer (T-Force) was used as criterion to validate a wearable device used to measure power, called PUSH (Balsalobre-Fernández, C., Kuzdub, M., Poveda-Ortiz, P., & del Campo-Vecino, J. (2016).

It should be noted that there is a small technical difference between a linear encoder and a linear position transducer, but a linear encoder is similar to a linear position transducer and can be used instead of the transducer in practical applications. Most encoders being used when testing athletes measure the distance the load or subject moves with a rotary encoder, while the most common type of transducer uses a potentiometer with a cable connected to it through a cable drum shaft (Sefastsson, 2011). Harris, Cronin, Taylor, Boris and Sheppard (2010) also notes that there are two types of rotational sensors used for measuring velocity and displacement of an object, linear position transducer, and the linear or rotary encoder.

Both the linear position transducers referenced in this thesis, and the linear encoder MuscleLab being used for the tests performed, function through connecting a cord to the weight being used. The same mathematical principles for calculating power output obviously apply to both methods. Therefore, the technical difference noted should not affect the measured values or purpose of this thesis.

Linear position transducer

Linear position transducers have been shown to be a valid system to estimate strength and power (Garnacho-Castaño, López-Lastra, Maté-Muñoz, 2015), and can measure displacement with a high accuracy (Cardinale, Newton & Nosaka, 2011). Linear position transducers are often used to measure strength and power in movements related to resistance exercise. They work by attaching a cord to either the equipment being used, or directly to the subject performing the exercise. Data on displacement, velocity of movement and acceleration is collected. Together with self-reported information on the mass of additional load being used, and in some cases the mass of the subject, data on power output can be generated (Garnacho-Castaño, López-Lastra, Maté-Muñoz, 2015).

The linear position transducer GymAware was considered to be a valid tool to measure peak and mean power output in different resistance exercises performed on a Smith machine. Correlations for all power measures were at least 0.97, with all correlations being statistically significant. The authors of the study concluded that there was almost no possibility that the difference between GymAware and the criterion would be relevant in any research on performance (Drinkwater, Galna, McKenna, Hunt, & Pyne, 2007).

Accelerometer

Accelerometers can be used to measure power through acceleration and mass data. They're small and easy to use, and can be attached either to equipment like a barbell, or directly to an athlete performing a movement. This makes accelerometers more versatile than a linear position transducer (Crewther et al, 2011). Accelerometers have also been shown in a previous study to be a reliable tool for measuring power output (Thompson & Bemben, 1999). Accelerometers are affordable, and have the added benefit of being wireless, unlike a linear encoder which might make the athlete concerned about cables getting in the way (Sato, Smith & Sands, 2009).

When the accelerometer Myotest was tested for validity using a force plate, it showed statistically significant correlations ranging from 0.66 to 0.90 for peak power when subjects performed squat jumps with external loads between 20 and 80 kg (Crewther et al, 2011). Myotest has also been tested in conjunction with test equipment consisting of a force plate paired with a linear transducer. The authors of the study concluded that Myotest showed a very high concurrent validity and reliability, compared with the criterion. R^2 correlations reached 0.92 and 0.82 for peak power in bench press throw and squat jump at 30 % of 1RM (Comstock et al, 2011).

PUSH is another accelerometer based tool that has recently had its ability to measure barbell velocity tested in a study using squats at loads from 25-85 % of 1RM. This study used a linear velocity transducer as criterion and showed very strong correlations for peak barbell velocity (r = 0.91, p < 0.001 (Balsalobre-Fernández, Kuzdub, Poveda-Ortiz & del Campo-Vecino, 2016).

Rational

While linear encoders are much cheaper than a force plate, they are still quite costly. For example, the MuscleLab equipment is priced (2017) at approximately 3000 euros. A sum of

3000 euros is a feasible sum to invest for colleges and elite sports teams, but it is a big investment for sports club on the smaller side and probably not very realistic for most individuals. Because of this, cheaper and more accessible alternatives to measure an athlete's power output have been developed, for example the accelerometer Beast Sensor which is priced at approximately 250 euros.

Purpose

The purpose of this study was to test the concurrent validity of the portable accelerometer Beast Sensor by measuring average power in explosive squatting and bench pressing at 40 % and 80 % of 1RM. The linear encoder MuscleLab was used as a criterion.

Research questions: 1. What is the concurrent validity between the linear encoder MuscleLab and the accelerometer based Beast Sensor for average power output during explosive squats and bench presses at 40 % and 80 % of 1RM? 2. Is there a statistically significant difference between the results obtained by MuscleLab and Beast Sensor for average power output at the different percentages of 1RM in explosive squats and bench presses at 40 % and 80 %?

Methods

Subjects

Seventeen subjects, five women and twelve men, started participation in the study and performed 1RM tests in the first session. Before the second session, two subjects dropped out due to time restraints, which led to 15 subjects completing the study.

Inclusion criteria were: at least six months experience of performing the exercises and an age between 20 and 45 years. Exclusion criteria: no injuries or diseases that hindered the subject's ability to safely perform the tests, or put the subjects at risk of exacerbating their symptoms. Additionally, the subjects were told to not train for 24 hours before the tests. No nutritional considerations were given.

To find subjects, written information about the study was made available through Facebook for members of a crossfit gym in southwestern Sweden. As the number of subjects available from the crossfit gym wasn't enough, two additional subjects with experience of the exercises included in the thesis were recruited from a university in the same area.

Study design

The thesis had a cross-sectional design and was a validation study. Subjects performed tests on two occasions. At the first session, the subjects tested their one repetition maximum (1RM) in the squat and bench press. At the second session 7-14 days later, the subjects performed squat and bench press at 40 % and 80 % of their 1RM. Average power output was assessed simultaneously with Beast Sensor and MuscleLab.

Test equipment

MusleLab

MuscleLab is a linear encoder that uses a wire that can be attached to a barbell. The speed and acceleration of the barbell is detected (Hilmersson, Edvardsson & Tornberg, 2015). The software MuscleLab uses the information to calculate several different metrics, including power output (MuscleLab manual, 2003).

The linear encoder MuscleLab demonstrated a high reliability when subjects performed counter movement jumps on a smith machine with an external load of 40 kg. Between two separate test sessions, measurements for average power showed a statistically significant strong correlation of $r_p = 0.97$ (Hilmersson, M., Edvardsson, I., & Tornberg, 2015). A high reliability of the MuscleLab system was also found when bench pressing loads ranging from 30 % to 80 % of 1RM on a Smith machine (Amonette et al, 2003).

MuscleLab has previously been used as the criterion for validating a new system to measure displacement and velocity (Buscà & Font, 2011). Since power can be calculated from displacement and velocity information, paired with manually entered input on the mass of the external load being used, this should ensure that MuscleLab can be considered a valid test instrument for assessing power as well.

Beast Sensor

The Beast Sensor is an accelerometer based portable tool that can be used to measure average power in different exercises. The sensor has a magnet which makes it possible to attach it to a barbell. Beast Sensor has a size of 20x19x40 mm and weighs 38 grams. It uses Bluetooth 4.0 to stream measured data to the Beast App, available for iPhone, iPad and Android devices (https://www.thisisbeast.com/en/product, 2017).

Beast Sensor hasn't previously been validated or used in any published scientific papers.

Exercise equipment

Barbells used by the male participants of the study were: Eleiko IWF Weightlifting Training Bar, 20 kg, men. The female participants used Eleiko IWF Weightlifting Training Bar, 15 kg, women (Eleiko Sport Group AB, Halmstad, Sweden). Weight plates were Eleiko IWF Weightlifting training discs. For squatting, an Eleiko Squat Stand was used. Bench presses were performed on an Eleiko PL Squat Stand/Bench.

Exercise technique

Before both the squat and bench press exercises, the subjects had the option of performing any stretches they needed to prepare for the lifts. They were free to use any equipment they wanted for extra support, such as weightlifting shoes, weight belt, or wrist wraps. The same general warmup before both test sessions was performed on an Assault AirBike, on which the subjects exercised for six minutes at a self-selected steady pace.

Squat

The squat is the most popular exercise to develop strength in the lower extremity (Jidovtseff et al, 2006). A squat can be performed starting with either a high or low bar position. In the high bar position, the barbell is held above the posterior deltoid, whereas the low bar position starts with the barbell across the posterior deltoids instead, using the trapezius muscle as added support. The grip for both versions is pronated, but wider in the low bar position than the high bar position (Baechle & Earle, 2008).

When the barbell is taken out of the squat rack, the athlete's feet should be placed shoulder-width apart, or wider, with toes slightly pointed outward. The movement then starts with the athlete flexing the hips and knees. To stand back up, the athlete extends at the hips and knees with the same pace, to maintain the angle of the torso. The repetition ends when the hips and knees are fully extended (Baechle & Earle, 2008). Some of the main muscles that perform a squat are gluteus maximus, hamstrings and quadriceps (Baechle & Earle, 2008).

The test leader supervised the depth of the squats. For a squat to be considered valid, the descent phase of the movement had to be continued until the top of the subject's thighs were parallel to the floor. This followed the procedure of Lake, Carden and Shorter (2012). The subjects were told to control the eccentric phase of the squat and not to bounce out of the bottom of the movement.

Bench press

The bench press is commonly used to assess and increase strength in the upper extremity (Padulo, Laffaye, Chaouachi & Chamari, 2015). To perform a bench press, the athlete starts by lying down in a supine position. Grip on the barbell should be pronated, slightly outside shoulder-width. The movement starts by taking the barbell out from its position on the bench press stand, so that the athlete's elbows are fully extended. The athlete then lowers the barbell to the chest, before pushing upward until the arms are fully extended again (Baechle & Earle, 2008). The main muscles that are working to perform the bench press are pectoralis major, anterior deltoids and triceps brachii (Baechle & Earle, 2008).

For the eccentric phase of the bench press, the subjects were instructed to lower the barbell to the chest in a controlled manner. After touching the chest with the barbell, the subjects pushed the bar back up for the concentric phase of the movement. The repetition was considered complete when the arms of the subject were fully extended (Garnacho-Castaño, López-Lastra, Maté-Muñoz, 2015). The test leader informed the subjects that they weren't allowed to bounce the barbell on the chest. For the heavier sets, the test leader was available to assist with lifting off the barbell from the bench press stand out to the starting position, if the subjects requested this help.

Procedures

One repetition maximum

One repetition maximum (1RM) is the highest amount of weight someone can lift once, while maintaining good form through a full range of motion (Miszko et al, 2003). At the first session, the subjects underwent a 1RM-testing procedure where squat was followed by bench press. The 1RM-test for both the squat and bench press followed the procedure of Wallace, Winchester and McGuigan (2006). The subjects estimated their 1RM to provide a weight to base the testing procedure on. The 1RM-testing started with ten repetitions at 50 % of the subject's estimated 1RM. They then continued with five repetitions at 70 %, three repetitions at 80 %, and one repetition at 90 % of their estimated 1RM. The subjects had up to three additional single repetition attempts to increase the weight and establish their 1RM. They decided how much weight to add themselves. There was three minutes rest for the sets up to 90 % of the 1RM and five minutes for the consecutive 1RM attempts. The highest amount of weight that the subject's lifted in the exercises was considered their 1RM.

Power test

The power test session took place 7-14 days after the 1RM-test. To ensure different velocities of the barbell during the squat and bench press, 40 % and 80 % of the subject's previously assessed 1RM were selected for measuring average power. These percentages of 1RM were similar to those used by Jidovtseff et al (2006), and the 85 % of 1RM that was the highest percentage lifted in a study by Garnacho-Castaño, López-Lastra and Maté-Muñoz (2015). As in similar studies previously performed, rest period between all sets were three minutes (Garnacho-Castaño, López-Lastra, Maté-Muñoz, 2015; Hilmersson, Edvardsson & Tornberg, 2015). There were also three minutes of rest after squat, before bench press testing commenced. Squats were performed first, followed by bench presses. Before the squat and bench press sets were assessed for average power output, the subjects performed an additional warm up of ten repetitions with just the barbell, followed by five repetitions at 40 % of their previously determined 1RM.

Average power output was measured during four sets each for squats and bench presses, two sets at 40 %, and two sets at 80 % of the subject's 1RM. Each set had three repetitions. To further standardize the instructions given for the exercises, the subjects were told to perform the concentric phase of the squats and bench presses as explosively as possible. Since a jump in weight from 40 % to 80 % of 1RM would be steep, and possibly increase injury risk, a set of three repetitions at 60 % of 1RM was added after the two sets at 40 % of 1RM. This set wasn't analyzed, and the subjects didn't have to perform it in an explosive manner.

The explosive repetitions at 40 % and 80 % of 1RM in squats and bench presses were simultaneously assessed for power output with MuscleLab and Beast Sensor. All six repetitions for each exercise were used in the statistical analysis. The wire of MuscleLab was connected to the barbell, two centimeters outside the outer knurl mark on the left side of the barbell. Beast Sensor was magnetically attached one centimeter outside of MuscleLab (see figure 1). Average power output was measured and reported in Watt.
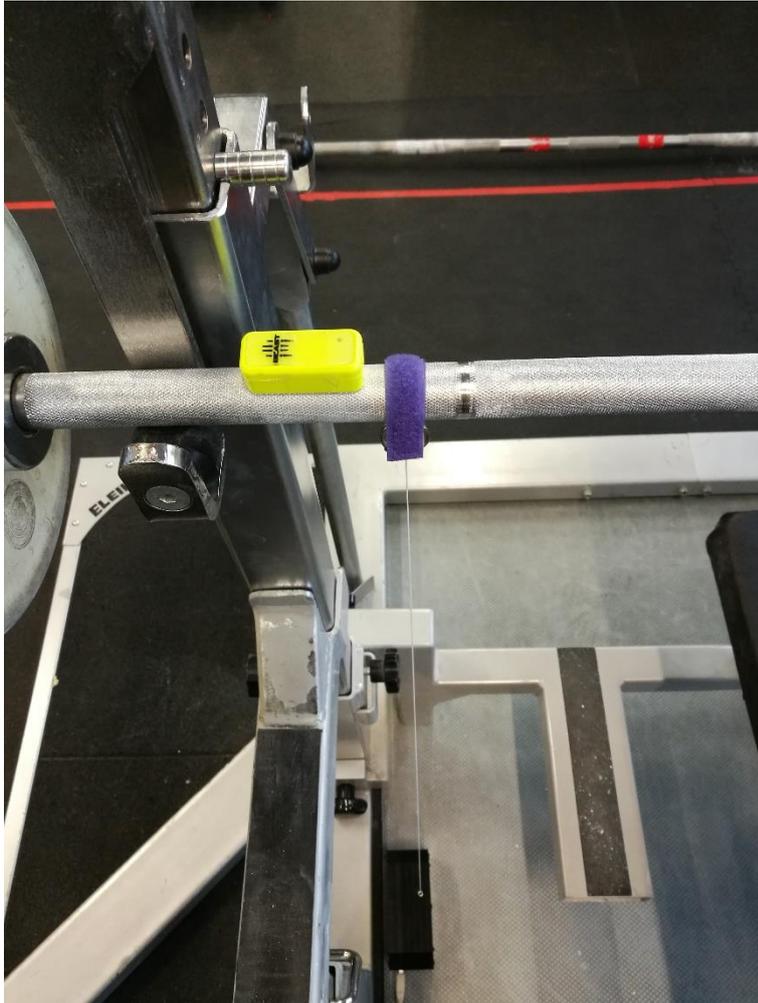
Figure 1. Setup of MuscleLab and Beast Sensor during the power testing session. The purple velcro connects MuscleLab to the barbell, the rectangle shaped yellow box is the Beast Sensor.

Ethical and social considerations

The ethical considerations of this thesis were based on the Helsinki declaration (World Medical Association, 2013). The subjects were given written information about the tests that were going to be performed (see appendix A). Performing a maximal effort test like the 1RM-test has an injury risk attached to it and the subjects were made aware of this. To decrease the injury risk associated with participation in the study, the subjects were free to use any equipment they needed, such as weightlifting shoes, lifting belt or wrist wraps.

It was also made clear to the subjects that all participation in the study was voluntary and that they were free to drop out anytime they pleased. A written consent form (see appendix B) was handed out and was signed and dated by each subject.

Some social considerations of this thesis is that the added knowledge on an accelerometer based test instrument to measure power can give athletes an affordable alternative to measure power output. An instrument for measuring power output can be used as a test to gauge efficacy of a training program, as well as for monitoring daily training and performance levels. This could lead to improved athletic performance.

Statistical analysis

The collected data was analyzed in SPSS (version 20). A Shapiro Wilks test was performed to see if the data was normally distributed. Statistical significance level was set at $p > 0.05$. A p-value higher than 0.05 was considered to confirm a normally distributed data set.

The data was considered non-normally distributed and a correlation analysis on the data was performed using the Spearman correlation test. As per Munro (1997), a correlation with r_s-value between 0.26 and 0.49 was seen as low, between 0.50 and 0.69 as moderate, between 0.70 and 0.89 as high. A correlation over 0.90 was seen as very high. The coefficient of determination and the p-values are presented along with the r_s-values. Statistical significance was set at $p < 0.05$.

McHorney and Tarlov (1995) have noted that there isn't the same kind of specific quantitative measure for validity as for reliability in terms of what's considered valid or not, but Hopkins (2002) writes that a correlation coefficient of 0.9 or higher can be used as a threshold of validity. Thus, for Beast Sensor to be considered as valid, the result for Spearman's rho had to be above 0.9.

Descriptive data are presented as median, min- and max values. The collected data was tested at group level for median values of power output. A Wilcoxon signed rank test was performed to detect any systematic difference between the average power output variable in MuscleLab and Beast Sensor.

Results

Fifteen subjects completed both test sessions included in this thesis, four women and eleven men, with a median age of 26 years and ages between 21 and 45. The subject's weights ranged from 51 to 98 kg with a median of 79 kg. Heights of the subjects were between 159 and 189 cm, with median height being 175 cm.

Table 2 (N=15). Medians and min-max values of age, height and weight for the subjects, and 1RM for squats and bench presses.

	Age	Height (cm)	Weight (kg)	1RM squats (kg)	1RM bench presses (kg)
Subjects	26 (21-45)	175 (159-189)	79 (51-98)	138 (60-175)	100 (36-132)

The results of the Wilcoxon signed rank test showed a statistically significant difference between MuscleLab and Beast Sensor for all variables. For squats at 40 % of 1RM, the p-value was 0.026. For all the other variables, squats at 40 % of 1RM as well as bench presses at 40 % and 80 %, p-values were below 0.01. Median and min-max values for average power output from the power tests of the second test session, can be seen in table 3, as well as p-values from the Wilcoxon signed rank test.

Table 3 (N=15). Median and min-max values of average power in squats and bench presses at 40 % and 80 % of 1RM, measured with MuscleLab and Beast Sensor. P-values from the Wilcoxon signed rank test.

Exercise and percentage of 1RM	MuscleLab (Watt)	Beast Sensor (Watt)	Wilcoxon signed rank test (p-value)
Squat, 40 % of 1RM	1328 (628-2023)	1393 (632-2604)	0.026
Squat, 80 % of 1RM	934 (424-1694)	777.5 (339-2592)	< 0.01
Bench press, 40 % of 1RM	423.5 (118-632)	438 (47-701)	< 0.01
Bench press, 80 % of 1RM	324 (128-515)	255.5 (54-606)	< 0.01

Concurrent validity of the Beast Sensor was analyzed. Table 4 shows Spearman's rho, p-values and coefficient of determination for the four analyzed data variables. See figure 2 for graphs of the correlations between Beast Sensor and MuscleLab. Beast sensor had a very high correlation with MuscleLab for squats at 40 % of 1RM, with Spearman's rho at 0.91. The Beast Sensor was considered valid for squats at 40 % of 1RM. When squatting at 80 % of 1RM, a low correlation ($r_s = 0.42$) between Beast Sensor and MuscleLab was found (see table 4 and figure 2). This was considered to be a low correlation, and Beast Sensor wasn't deemed valid at 80 % of 1RM in squats.

For bench pressing at 40 % of 1RM, the correlation was high between Beast Sensor and MuscleLab, with Spearman's rho at 0.86 (see table 4 and figure 2). When bench press was being performed at 80 % of 1RM, correlation between Beast Sensor and MuscleLab was high,

with r_s at 0.74 (see table 4 and figure 2). All correlations were statistically significant, with a p-value of < 0.01. The correlations for bench presses didn't reach the threshold for validity and Beast Sensor wasn't considered valid for either 40 % or 80 % of 1RM.

Table 4 (N=15). Spearman's correlation coefficient for MuscleLab and Beast Sensor at 40 % and 80 % of 1RM for the squat and bench press, coefficient of determination, and p-values for the correlations.

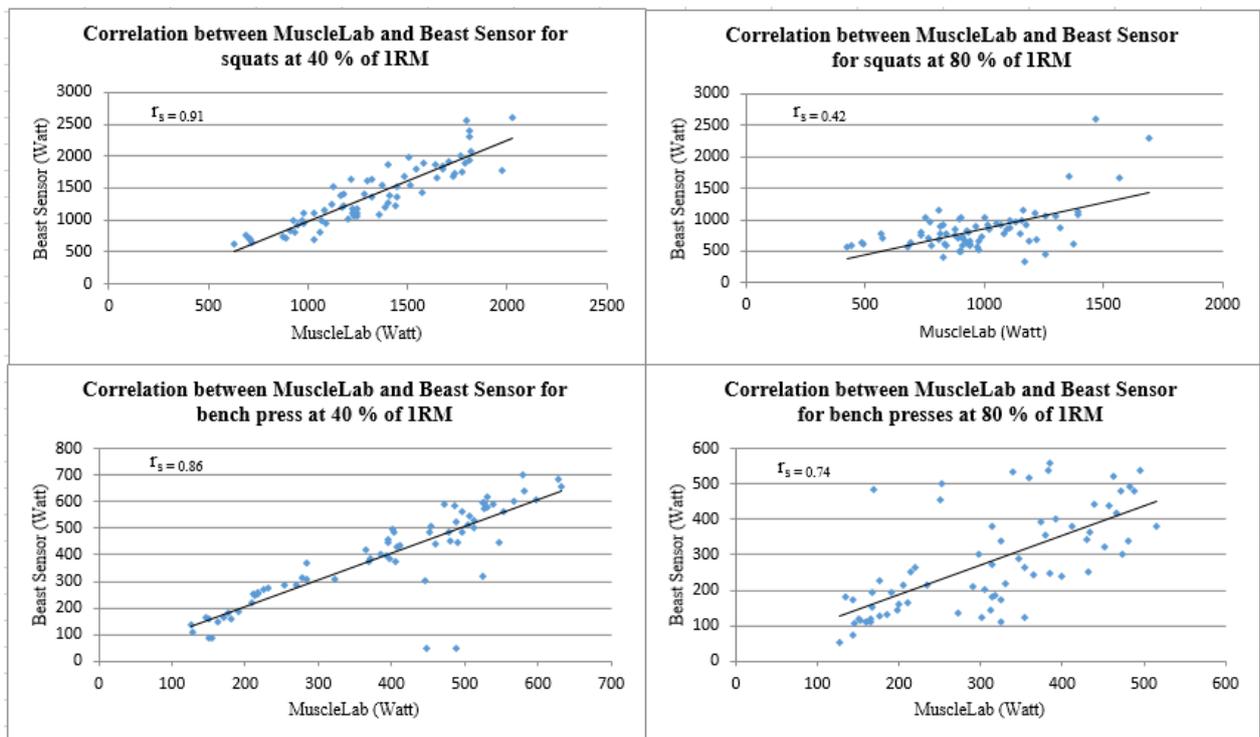| Exercise and percentage of 1RM	Spearman's rho	P-value	Coefficient of determination
Squat, 40 % of 1RM	0.91	< 0.01	0.83
Squat, 80 % of 1RM	0.42	< 0.01	0.18
Bench press, 40 % of 1RM	0.86	< 0.01	0.74
Bench press, 80 % of 1RM	0.74	< 0.01	0.55

Figure 2. Correlations between MuscleLab and Beast Sensor for explosive squats and bench presses at 40 % and 80 % of 1RM, with trendline and Spearman's rho.

Discussion

The statistical analysis of the concurrent validity of the Beast Sensor showed high or very high correlations with MuscleLab for average power output of explosive squats at 40 % of or 1RM (r_s = 0.91) and for explosive bench presses at 40 % (r_s = 0.86) and 80 % or 1RM (r_s = 0.74). For the squats performed at 80 % of 1RM, contradicting results were found, and the correlation was considered low (r_s = 0.42). Beast Sensor was considered valid for measuring average power output at 40 % of 1RM in squats, but neither for squats at 80 % of 1RM, nor bench presses at 40 % or 80 % of 1RM.

Results discussion

The correlation coefficients of this thesis were similar to previous findings where the validity of the accelerometer Myotest to measure power was investigated. The Myotest accelerometer was tested for validity by using squats jumps with an external loads, using a force plate as criterion. Myotest showed statistically significant correlations of 0.66 for 20 kg, 0.88 for 40 kg, 0.82 for 60 kg, and 0.90 for 80 kg (Crewther et al, 2011). Myotest has also resulted in correlations above 0.90 when squat jumps and bench press throws in a smith machine at 30 % of 1RM were measured using a force plate paired with a linear transducer as criterion (Comstock et al, 2011). The study investigating the validity of the Myotest measured peak power, while the Beast Sensor investigated in this thesis measured average power. Balsalobre-Fernández, Kuzdub, Poveda-Ortiz and del Campo-Vecino (2016) found very high correlations (r = 0.91) for barbell velocity in squats using a smith machine, with loads from 25-85 % of 1RM with the accelerometer PUSH, but the results for each different load were not reported.

Except for the study by Crewther er al (2011), none of these studies reported any correlations below 0.9 when validating accelerometer based test instruments. What these studies, as well as many others measuring power or barbell velocities, have in common is that they used a Smith machine for their tests. A Smith machine limits the barbell to moving only vertically which could possible increase the correlation coefficients.

The low correlation between the MuscleLab and Beast Sensor found in this thesis for average power output of squats at 80 % of 1RM is difficult to explain. In the bench press, there was also a lower correlation at 80 % than 40 %, but the difference was a lot smaller and the correlation was still considered high. These findings indicate that the Beast Sensor was more accurate at higher velocities than lower, which contradicts the study by Crewther et al (2011)

where a much higher correlation was found with the lower barbell velocity at the external load of 80 kg, than with 20 kg.

Free ranging barbell instead of Smith machine

In this thesis free weights were used both in the squat and bench press exercise. When using free weights, the barbell can move both vertically and horizontally, which could be a potential source of error (Crewther et al, 2011). In contrast, most other studies validating power equipment have used a smith machine instead, with a fixed barbell which can only move vertically (Cormie, McBride & McCaulley (2007). Movement of the body in the frontal or sagittal plane when squatting, could potentially affect the capability of a test instrument to accurately measure vertical displacement and velocity of a barbell (Comstock et al, 2011). This is also a possible reason for the lower correlation this thesis found for squats performed at 80 % of 1RM. If the subjects struggled with some of their repetitions at that load, there could potentially have been a larger horizontal displacement of the barbell than at 40 % of 1RM.

The test procedure of this thesis was deliberately set up to use a free weight barbell instead of a Smith machine. One reason for this was to try to add a slightly different perspective to the on-going evaluation of test instruments to measure power output. A lot more people also have access to free weights than a smith machine, which makes the Beast Sensor useful to a larger number of people if it is considered a valid tool to measure power in exercises using free weight. The final and most important reason for the choice of a free weight exercise was that most athletes probably rarely use a Smith machine in their training. Therefore, any findings of a study using exercises in a Smith machine couldn't automatically be applied to a free weight version of the same exercise.

Beast Sensor missing repetitions

The results for the concurrent validity of the Beast Sensor didn't show the whole story. A big problem with the device was that it repeatedly missed repetitions. This made the power tests challenging to the test leaders who in real time had to observe the measurements in MuscleLab and Beast Sensor simultaneously to make sure a repetition registered a value in both the MuscleLab software and the Beast Sensor app.

With 15 subjects performing 24 reps each, there should have been 360 measured repetitions. A total of 38 repetitions were missing with Beast Sensor, roughly ten percent of all repetitions. This was a potential confounder for the statistical analysis. It should be noted that

only three of these missed repetitions occurred at 40 % of 1RM in squats. Coupled with the very high correlations for the power measurements at this intensity of squats, this further solidifies the validity of Beast Sensor for measuring average power output at 40 % of 1RM in explosive squats.

When the analysis was performed in SPSS, cases was excluded pairwise which hopefully decreased the risk of the missing repetitions being a large confounder. Some shorter tests of the Beast Sensor were made before the thesis started, but a more controlled pilot study would have been a big help in trying to figure out the problem of missing repetitions before the test sessions had already started.

The missing repetitions also negatively affected the feasibility of using the device in any scientific setting, as well as in any setting with elite athletes needing a reliable test instrument to measure power. These findings demonstrated that a high concurrent validity of a test instrument doesn't necessarily mean that the statistical results of a study proved the efficacy of the studied instrument.

Methods discussion

The planned procedure of the tests was to have the two sessions separated by a week, but this scheduling was simply not manageable due to lack of time on the subject's behalf. The procedure was changed to putting the second session 7-14 days later, which gave a range of seven possible days for the subjects to complete the testing procedures.

A potential source of error for the statistical analysis was that all six repetitions for each data variable, 40 % and 80 % of 1RM in both squats and bench presses, were included in the analysis. Because of this, there were a lot more values for average power output analyzed than the number of study participants warranted, which could be a reason for the p-values being really low. It also added to the risk of the values for Spearman's rho being higher than they should have been, if for example only the highest average power output for each data variable was used for the statistical analysis. This thesis set out to test the validity of the Beast Sensor, not the reliability. However, Laake, Benestad and Olsen (2007, p. 109) write about reliability and note that "repeatability is understood as the degree to which the same results are seen when measurements are repeated under identical experimental conditions." By using all six repetitions for the data variables included in this thesis, the conditions resemble those Laake, Benestad and Olsen (2007) used to describe repeatability. In the validation study of the

accelerometer PUSH by Balsalobre-Fernández, Kuzdub, Poveda-Ortiz and del Campo-Vecino (2016), the authors used all three values obtained from their ten study participants for five different assessed variable for statistical analysis. They performed a single Pearson's correlation test for all 150 obtained values combined to test the validity of PUSH. This indicates that there might not be a scientific consensus on how to perform the correlation analysis in validation studies like this thesis.

The tests for which this thesis was based on were made in collaboration with another student of Halmstad University. The data collected for squats was shared, but the other student added power cleans to his thesis. This was the main reason for performing the tests of this thesis at a crossfit gym instead of the laboratory at Halmstad University. The equipment of the gym was better suited for power cleans than that of the laboratory. It was also agreed that it would be easier to recruit enough test subjects with experience of power cleans, in addition to squats and bench presses, at the crossfit gym.

The addition of power cleans to the test battery of the thesis also affected the order of exercises being tested. To limit the amount of test sessions to two, 1RM tests for all the exercises were performed at the first session, while power tests for all the exercises were performed at the second session. This made the test sessions quite long and challenging for the test subjects. Instead of randomizing the order of the exercises, squats were put first, followed by bench presses, before finishing with power cleans. Putting the exercise focusing on the upper extremities in the middle was thought to make it easier for the subjects, whose legs would have a chance to recover slightly from the squats before power cleans would be performed.

The main caveat with having the test sessions take place at a crossfit gym was that the environment wasn't really suited for scientific testing. Equipment wasn't always readily available which in some instances increased rest periods and the general flow of the tests. The gym was also often crowded at the evening sessions, as well as noisy from loud music being played for group workouts or competitions.

The high or very high correlations for three of the four measured variables, combined with the number of missed repetitions by the Beast Sensor set up some further studies to be performed. A wider range of percentages of 1RM need to be examined to ensure that the Beast Sensor is tested at different barbell velocities. The reliability of the Beast Sensor also needs to be

assessed, perhaps with a research question like: What is the level of reliability of the Beast Sensor?

Conclusions

The Beast Sensor demonstrated high or very high correlations with the criterion MuscleLab for average power output of explosive squats at 40 % of 1RM ($r_s = 0.91$), and for explosive bench presses at 40 % ($r_s = 0.86$) and 80 % or 1RM ($r_s = 0.74$), with MuscleLab used as criterion. However, for explosive squats at 80 % of 1RM, the correlation was low ($r_s = 0.42$). For measuring average power output of explosive squats at 40 % of 1RM, Beast Sensor was considered valid, but neither at 80 % of 1RM in squats, nor at 40 % or 80 % of 1RM in bench presses. Except for at 40 % of 1RM in squats, Beast Sensor missed a substantial amount of repetitions. Futher studies examining the reliability of the Beast Sensor are therefore needed.

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Appendices

Appendix A. Information to subjects.

Studie av bärbara metoder för att mäta explosivitet.

Information

Effektutveckling är ett mått på explosivitet (hur snabbt man kan skapa kraft) och kan användas för att utvärdera en atlet. Explosivitet är en relevant egenskap för ett flertal olika idrotter där det krävs snabba fartökningar, sprinter och hopp. Det är även viktigt för olympiska lyftare och idrottare inom kontaktsporter. En atlets effektutveckling kan även vara ett sätt att följa atleten under en tävlingssäsong för att mäta prestationsförmågan. Effektutveckling kan mätas genom att se hur mycket vikt en atlet förflyttar över en viss tid.

Syften med denna studie är att se hur starkt sambandet är mellan effektutveckling uppmätt med två olika mätmetoder. En som kallas linear encoder där ett snöre från en mätare fästs på stången och mäter avståndet stången rör sig och hur fort det sker. Den andra metoden är helt bärbar och innebär att en liten sändare fästs på stången och även den mäter avstånd och hastighet på stången. Övningarna som ska undersökas är bänkpress, knäböj samt frivändning.

Studien fokuserar på personer i åldern 18-45 med minst sex månaders erfarenhet av samtliga övningar som ska undersökas. Eftersom Du stämmer in på dessa kriterier tillfrågas Du att delta i denna studie.

Testerna kommer att genomföras vid två tillfällen, med en veckas mellanrum, och kommer ta ca 60 minuter. Din längd, vikt samt information om din ålder samlas in vid första tillfället.

Deltagande i denna studie innebär en viss skaderisk på grund av den maximala prestation som utförs. Testledare kommer att finnas på plats vid testtillfällena och instruera utförandet av testerna för att säkerställa att de utförs korrekt så att skaderisken minskar. Om Du som testperson har sjukdom eller skada som kan förvärras av deltagande i studien kan Du inte delta.

Med hjälp av studiens resultat kan du utvärdera din explosivitet. Du kommer testa din maximala styrka i samtliga övningar och får därmed information om din styrka. Effektutveckling kommer mätas i form av antal uppmätta Watt.

Dina resultat från studien kommer vara konfidentiella och kommer inte att kunna kopplas till dig personligen. Studieresultaten i sin helhet kommer att redovisas på gruppnivå i form av en C-uppsats på högskoleprogrammet Biomedicin med inriktning fysisk träning på Halmstad Högskola. Data från studien kommer förvaras på ett USB-minne som under studiens gång förvaras hos testledare. Efter studiens avslut kommer USB-minnet återföras till Halmstad Högskola där det kommer förvaras inlåst.

Ditt deltagande i studien är helt frivilligt och Du har när som helst rätten att avbryta ditt deltagande. Du meddelar då testledaren som kommer att radera befintlig data från dina resultat.

Appendix B. Informed consent.

Samtycke

Nedan ger Du ditt samtycke till att delta i studien gällande effektutveckling. Läs noggrant igenom informationen och signera längst ner på denna sida för att ge ditt medgivande till deltagande.

- Jag har tagit del av informationen kring studien och förstår vad den innefattar.
- Jag har fått ställa de frågor jag vill och vet vem jag ska kontakta vid ytterligare frågor.
- Mitt deltagande är frivilligt i studien och kan när som helst avbryta mitt deltagande utan att ange orsak.
- Jag tillåter att mina personuppgifter registreras enligt den information jag tagit del av och att insamlad data om mig förvaras och hanteras av ansvariga för studien.

Med vänlig hälsning

Jonas Bergenblad

Ludvig Eriksson

För frågor angående studien nås vi på jonber14@student.hh.se eller luderi14@student.hh.se

Handledare: Emma Haglund (emma.haglund@hh.se) och Mia Andersson (mia.andersson@spenshult.se)

Datum/ort _____

Underskrift   _____

Namnförtydligande

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