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Upper body strength and endurance and its relationship with freestyle swim performance in elite swimmers

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Halmstad University
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Abstract

Background: Strength is considered an important part in swimming and is usually included in training programs for swimmers. However, studies assessing the relationship between muscle strength, muscle endurance and swim performance are not many and have showed different results.

Aim: The aim of this study was to assess the correlation between bench press, pull-up and 400 meter freestyle swim performance in elite swimmers.

Method: The subjects (n=15, age 16-20) performed a one repetition maximum (1RM) bench press test to measure maximal muscle strength and to measure muscle endurance the subjects performed as many pull-up repetitions as possible during 30 seconds. A velocity four (V4) speed test was performed to assess swim performance by measuring time over covered distance and blood lactate levels.

Results: The results of this study showed a moderate correlation (r=-0.54) between one repetition maximum in bench press and 400 meter freestyle swim performance. It showed a strong correlation (r=-0.63) between number of pull-ups repetitions during 30 seconds and 400 meter freestyle swim performance.

Conclusion: These results suggest that upper body strength contributes to swim performance over 400 meter. The stronger correlation between pull-ups and swimming may indicate that muscle endurance of m. latissimus dorsi and the back muscles may be important to incorporate in a training program since it has shown to have a strong correlation with swim performance at 400 meters.

Bakgrund: Styrka anses vara en viktig del i simning och är ofta inkluderat i träningsprogram för simmare. Dock har endast ett mindre antal studier undersökt relationen mellan muskelstyrka, muskel uthållighet och simprestation och de som har gjort det visar olika resultat.

Syfte: Syftet med denna studie var att utvärdera korrelationen mellan bänkpress, pull-ups och 400m simprestation hos elitsimmare.

Metod: Deltagarna (n=15, ålder 16-20) utförde ett en repetition maximum (1RM) i bänkpress för att mäta maximal muskel styrka och för att mäta muskeluthållighet utförde deltagarna så många pull-ups repetitioner som möjligt under 30 sekunder. Ett velocity four (V4) hastighets test utfördes för att utvärdera simprestation genom att mäta tid över simmad distans och blod laktat värden.

Resultat: Resultatet i denna studie visade på en moderat korrelation (r=-0,54) mellan en repetition maximum i bänkpress och 400 meter fristil simprestation. Den visade på en stark korrelation (r=-0,63) mellan antalet pull-ups repetitioner under 30 sekunder och 400 meter fristil simprestation.

Konklusion: Dessa resultat tyder på att överkroppsstyrka bidrar till simprestation över 400 meter. Den starkare korrelationen mellan pull-ups och simning kan indikera att muskeluthållighet hos m. latisimus dorsi och ryggmusklerna kan vara viktigt att lägga in i ett träningsprogram då det visat på en stark korrelation till simprestation på distansen 400 meter.

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Introduction

A swimmer´s strength is considered one of the biggest factors that influences their swim performance, strength training can also help to improve an athletes swimming technique (Garrido, Marinho, Reis, Van Den Tillaar, Costa, Silva, & Marques, 2010). For these reasons a combination of strength- and endurance training is often used in swimmers training programs (Garrido et al., 2010; Aspenes, Kjendlie, Hoff, & Helgerud, 2009). However, the number of studies that have assessed the relationship between muscle strength, muscle endurance and swim performance are few. The studies that have been made on this subject have shown different results with both stronger and weaker correlations. These studies have also mostly tested maximal muscle strength and swim performance on shorter distances of 15m to 100m. Therefore, this present study will further investigate the relationships between muscle strength and endurance and swim performance at a longer distance of 400m.

Background

Swimming

Swimming can be divided in to two parts, technical performance and the activity of the muscles (Mattson, et al., 2015). Strength have been suggested to be a factor that improves swimming performance along with anthropometrics, biomechanics, hydrodynamics and energetics (Garrido et al., 2010; Morouço, Neiva, González-Badillo, Garrido, Marinho, & Marques, 2011). A swimmer´s strength and speed are considerd two of the biggest factors that influences their swim performance and strength training can help to improve an athletes swimming technique (Garrido et al., 2010). Therefore, a combination of strength- and endurance training is often used in swimmers training programs (Garrido et al., 2010; Aspenes et al., 2009). For a successful swimming performance VO2max are also considered an important factor (Young-Hyeon, Jae-Ho, & Suk Min, 2016). During the propulsive underwater phase of freestyle swimming, m. Latissimus dorsi and m. Pectoralis major has proven to be important. To maintaining swimming speed m. Latissimus dorsi and m. Pectoralis major along with m. Biceps brachii, m. Triceps brachii and m. Carpi ulnaris are key muscles. M. Serratus anterior plays an important role in the preparation for the next propulsive phase and shoulder joint stability (Lomax, Tasker, & Bostanci, 2015). Freestyle swimming requires the athlete to have significant strength in a closed kinetic chain pull and push type of exercises, for example pull-ups and dips (Coyne, Tran, Secomb, Lundgren, Farley, Newton, & Sheppard, 2015). Pull-ups are often included in test batteries to assess physical performance (Ricci, Figura, Felici, & Marchetti, 1988; Larsson et al., 2015).

The swimmers speed is also important during swimming and is determined by the water resistance and the propulsive power of the movement. While swimming the head, hips and heels should be in approximately the same horizontal line (Mattson, et al., 2015). Swimming requires an athlete to generate horizontal movement while also maintaining buoyancy. Fat floats more easily in water than muscle and bones that sinks. Women generally have a higher percent of body fat than men and therefore generally expend less energy to stay afloat and gain a hydrodynamic lift. Women also tend to have their body fat more peripheral, making them more streamlined caused by their arms and legs floating higher. Having legs at a deeper position in the water increases body drag and decreases swimming economy (McArdle, Katch, & Katch, 2015).

Besides maintaining buoyancy, a swimmer must also overcome the drag force. The swimmer´s shape, size and velocity along with the fluid determine the amount of drag. The total drag force consists of three parts, the wave drag, skin friction drag and viscous pressure drag. The wave drag is caused by the waves that the athlete produces while swimming. This drag has a greater effect at higher swimming speeds and does not have a significant effect during slower speeds. When the water slides over the skin surface the skin friction drag is produced. This type of drag does have a small contribution, even at higher velocities, to the total drag. However, by shaving, the skin friction drag can be reduced and thereby the energy expenditure decreases. The viscous pressure drag is caused by the differences in pressures behind and in front of the swimmer, which prevents the forward movement at slow velocities. Swimmers who have a good streamline stroke technique may experience less drag and the design of a swimsuit can also reduce the overall drag (McArdle et al., 2015).

Muscle fibers

As mentioned previously strength is an important factor in swim performance. Muscle strength can be measured in different ways but to measure maximal muscle strength usually a one repetitions maximum test is performed (Lavinger, Goodman, Hare, Jerums, Toia, & Selig, 2009). A test where the subjects perform as many repetitions as possible of one exercise is commonly used to measure muscle endurance (Hasan, Kamal, & Hussein, 2016; Coyne et al., 2015). The muscles are built up by muscle fibers and are divided into two groups, slow-twitch and fast-twitch fibers. The muscle fibers are specialized for a specific type of activity, strength or endurance. The amount of each of these fibers in a person's muscles may indicate which activity this person may perform best at. The muscle fibers are named after their twitch time, fast-twitch fibers develop force and relax fast whilst the slow-twitch fibers develop force and relax slower. In addition, the fibers can be divided in to type I (slow-twitch), type IIa (fast-twitch), and type IIb (fast-twitch). These fibers differ in size, contraction and relaxation speed, aerobic and anaerobic enzyme content, power output, endurance and a few other factors. The physiological characteristics determent which motor unit is recruited for what activity. A motor unit consists of a motor neuron and the muscle fibers that the neuron innervates. The slow-twitch motor units with their endurance capacity, efficiency and resistance to fatigue are recruited during for example a long-distance swim. The fast-twitch units are recruited during a sprint or when a maximal effort is required. However, both types of units are always involved more or less. During a 200m swim for example the fast-twitch units are more involved in the beginning and the slow-twitch takes over towards the end. Within all the different muscle fibers is where the contraction takes place, making the muscle shorten and produce power (Baechle & Earle, 2008).

Muscle contraction

A muscle contraction happens when actin filaments at each end of the sarcomere slide on the myosin filaments towards each other. At the same time also pulling the Z-disk toward the center of the sarcomere, M-line, and thereby shortening the muscle fiber (Baechle & Earle, 2008). A contraction starts with a nerve impulse reaching the axon terminal and calcium channels opens in the axon membrane. The entry of calcium starts the release of acetylcholine (ACh) in to the synaptic gap. The ACh binds to receptors in the sarcolemma and triggers an action potential (AP) in the muscle fiber and the AP travels along the sarcolemma and then down the T-tubules. Calcium ions (Ca2+) are released from the sarcoplasmic reticulum and binds to troponin. Troponin changes its shape and exposes binding sites on the actin filaments. The series of events when myosin heads pull actin filaments towards the center of the sarcomere is called the cross-bridge cycle. This starts with a active myosin head attaching to actin filament and forming a cross bridge. Then adenosine diphosphate (ADP) and Pi (inorganic phosphate) are released making the myosin head pivot and bend, thereby pulling the actin filaments towards the midline. ATP (adenosine triphosphate) attaches to myosin making the myosin head detach from actin. ATP the hydrolysis to ADP and Pi, the myosin head then return to its original position. For the cross-bridge cycle to continue ATP needs to be available and Ca2+ needs to be bound to troponin (Marieb & Hoehn, 2014).

The number of cross bridges that are attached determines the force of the muscle contraction and the number of cross bridges attached are effected by four factors. The number of muscle fibers recruited is one factor, a higher number of motor units recruited results in a greater muscle force. A muscle with larger muscle fibers and a larger cross-sectional area can produce more tension and strength, also the most powerful movements are produced by the large fibers of large motor units. A greater muscle force can also be affected by a more rapidly stimulated muscle and lastly the degree of muscle stretch can affect the force generated by the muscle. When the muscle is slightly stretched the ideal length-tension relationship occurs within the sarcomere and the overlap of the myosin and actin filaments is optimal. To perform a muscle contractions energy is needed and the body can produce energy through different pathways (Marieb & Hoehn, 2014).

Energy systems

The energy used to perform work comes from the breakdown of the chemical bonds in the macronutrients protein, carbohydrates and fats (Baechle & Earle, 2008). In the cells, ATP is the primary energy transferring molecule and the energy stored in the bonds of ATP can immediately be used by the cells in the body (Marieb & Hoehn, 2014). In the bond between the two phosphate groups of the molecule adenosine triphosphate (ATP) a large amount of energy is stored. The production of ATP must occur in the cell because the muscle cells can only store a limited amount at a time and a constant supply of ATP is needed for muscle actions. ATP can be generated through three different systems, the phosphagen system, glycolysis and the oxidative system. The phosphagen system and the first part of the glycolysis are anaerobic meaning they do not require the presence of oxygen. The oxidative system, including the Krebs cycle and electron transport chain, does need oxygen to occur. These systems are active at the same time; however, the extent of their contribution depends on the intensity and duration of an activity (Baechle & Earle, 2008). During a muscle contraction ATP supplies the energy, but muscles can only store a limited amount of ATP that may last for four to six seconds of an exercise. The only energy sources used directly for contraction is ATP, therefor to be able to continue contractions it must be regenerated at the same rate that it is being broken down. In the muscle fiber after ATP has been broken down to ADP and inorganic phosphate it can be regenerated by three different pathways, direct phosphorylation, the anaerobic- or aerobic pathway. The direct phosphorylation uses creatine phosphate (CP), stored in the muscle, to regenerate ATP. The phosphate from CP binds to ADP and makes ATP and creatine, each CP provides one ATP and one creatine. This pathway supply energy for about 15 seconds and does not require oxygen to be present (Marieb & Hoehn, 2014). Activities like heavy weight lifting, 100m sprint and 25m swim requires immediate energy. This energy is almost exclusively supplied by adenosine triphosphate (ATP) and phosphocreatine (PCr) during the immediate energy system. Skeletal muscles contain tree to eight mmol of ATP per kilogram and four to five times more PCr. Sufficient stores of phosphagen can supply energy for about five to eight seconds during sprint running (McArdle et al., 2015).

The anaerobic pathway uses glucose as energy source and from one glucose molecule, two ATPs are generated along with lactic acid. Glycolysis is the first part of the breakdown where glucose is broken down to two pyruvic acid molecules and releases two ATP. During the absence of oxygen, the pyruvic acid is converted in to lactic acid. Most of this lactic acid diffuses from the muscle into the bloodstream, where it is picked up by the liver, heart and kidney and used as an energy source (Hall, Rajasekaran, Thomsen, & Peterson, 2016; Marieb & Hoehn, 2014). This pathway provide energy for about 30 to 40s and does not require oxygen (Marieb & Hoehn, 2014). It contributes to ATP generation during most activities, both shorter and longer ones, but are the biggest contributor during 400m running and 100m swimming among others (McArdle et al., 2015). The third pathway, aerobic pathway, uses glucose, pyruvic acid, free fatty acids and amino acids as energy sources. This pathway requires oxygen, takes place in the mitochondria and completely breaks down the glucose molecule. For every broken-down glucose molecule, the end products are approximately 32 ATPs, carbon dioxide and water. The aerobic pathway provides energy for hours (Marieb & Hoehn, 2014). During intense activities that continue longer than a few seconds, aerobic metabolism supplies nearly all the energy (McArdle et al., 2015).

Lactate

As mentioned above lactic acid is produced during the anaerobic pathway. The amount of blood lactate accumulated during an activity is depended on its intensity, but it does not accumulate at all levels (McArdle et al., 2015). Besides the exercise intensity, lactate accumulation can also depend on muscle fiber type, state of training, initial glycogen levels and exercise duration (Baechle & Earle, 2008). During light and moderate activities blood lactate oxidizes at the same rate as it is produced (McArdle et al., 2015). A person’s ability to clear the lactate reflects their ability to recover. The clearance rate of lactate after an exercise can be increased by doing a light activity. After high-intensity exercises the accumulation of blood lactate is greater than after a low-intensity continuous exercise. When exercising at the same resistance, trained people have lower blood lactate concentration than untrained people (Baechle & Earle, 2008). The lactate that is produced in one part of the working muscle can be oxidized by muscle fibers that have a high oxidative capacity within the same muscle or nearby muscles like the heart or other tissues. The level of blood lactate remains stable if the lactate oxidation equals the lactate production. By doing aerobic training the accumulation of lactate can be delayed to a higher intensity level. The lactate accumulation can be explained by the enzyme lactate dehydrogenase (LDH). The LDH in the fast-twitch muscle fibers mostly converts pyruvate in to lactate and the LDH in the slow-twitch muscle fibers mostly converts lactate in to pyruvate. Lactate formation gets greater during increased exercise intensity do to the recruitment of fast-twitch fibers (McArdle et al., 2015).

The lactate threshold (LT) is the point where the blood lactate increases abruptly above the baseline concentration. LT is often used as an indicator of the anaerobic threshold and correlates well with the ventilation threshold (Hall et.al., 2016; Baechle & Earle, 2008). This occurs at a higher maximum oxygen consumption (VO2max) in trained individuals than untrained individuals (McArdle et al., 2015). In trained athletes, the LT usually begins at 70-80% of maximal oxygen uptake and at 50-60% in untrained individuals. When the concentration of blood lactate reaches 4 mmol/L it is called onset of blood lactate accumulation (OBLA). To make the lactic accumulation, LT and OBLA, occur at a higher percentage of maximal oxygen uptake studies have suggested to train at intensities near or above LT and OBLA (Hall et.al., 2016; Baechle & Earle, 2008). OBLA have previously been used as an indirect subscript of maximal lactate steady state (Figueira, Caputo, Pelarigo, & Denadai, 2008), it has also been used as an indicator of exercise intensity and an athlete's performance (Garcia-Tabar, Izquierdo, & Gorostiaga, 2017; Chmura & Nazar, 2010). By identifying a workload where lactate levels are fixed at 4 mmol/l it has been suggested that endurance performance can be predicted (Pallarés, Morán-Navarro, Ortega, Fernández-Elías, & Mora-Rodriguez, 2016). Blood lactate levels of 4 mmol/L have shown to be a predictor of 400m swim performance and a valid indicator of swim-specific aerobic endurance (Rodíguez, Moreno, & Keskinen, 2003; Olbrecht, Madsen, Mader, Liesen, & Hollmann, 1985; Rodríguez, 1994).

Studies on swimming and strength

A combination of strength- and aerobic training is often used in swim training programs (Garrido et al., 2010; Aspenes et al., 2009) and studies have previously research this. An intervention of 11-weeks high aerobic intensity and maximal strength training program, on men and women, showed an improved 400m freestyle swimming performance. The same study also tested shorter distances but showed no change in performance of 50m and 100m. Therefore, strength training might be important for improving middle distance swimming due to the improved 400m freestyle correlation with improved tethered swimming force (Aspenes et al., 2009). A study with an eight weeks' strength training program combined with aerobic swim training only showed a slight improvement in 25m and 50m swim performance (Garrido, Marinho, Barbosa, Costa, Silva, Perez-Tupin, & Marques, 2010). Other individuals performed a 12-week intervention of one out of three different training program, a strength (S) program, an assisted and resisted swim (ARS) program, an aerobic cycling (C) program, along with their regular swim training. After this intervention, an increase in swimming velocity and strength of elbow extensors and flexors was found in the S and ARS group, also an increase in stroke rate in the ARS group. These findings suggest that a training program combining swimming with in-water resisted and assisted exercises or dry land strength exercises may increase sprint swimming performance more than swim training alone (Gilrold, Maurin, Dugué, Chatard, & Millet, 2007). It has also been proven that a dry-land strength program combined with swimming may lead to increased sprint swim performance more than swimming alone (Girold, Jalab, Bernard, Carette, Kemoun, & Dugué, 2012).

When testing the freestyle swim performance at 15, 25, 50 and 100m and its correlation to performance in bench press and bent-over row it showed to have a strong correlation (r=0.77 - r=0.85). The strength test was 1RM tests and the swim test recorded time over covered distance (N=21, age 15-19) (Keiner, Yaghobi, Sander, Wirth, & Hartmann, 2015). A study (N=60, age 16 to 35) tested a 6-repetitive maximum (6RM) of bench press and the time of 50 and 300m freestyle swim tests. This study however, did not show a significant correlation between swimming performance and bench press (50m: r=0.018, 300m: r=0.081) (Sandhu, Kaur, & Shenoy, 2012). An additional study (N=28, age 12) assessed the correlation between bench press and freestyle swim performance. The strength test was also a 6RM and the swim test recorded time over 25 and 50m. These correlations were moderate (25m: r=0.58, 50m: r=0.59) (Garrido et al., 2010).

In conclusion, strength is considered one of the more important factors for swim performance, yet few studies have assessed the correlation between dry-land muscle strength and swimming performance. The findings in earlier studies are inconclusive, the correlations in these studies have varied and showed both stronger and weaker correlations. They have also used mostly short swim distances, maximal muscle strength and only recorded time over covered distance during the swim tests. Since these studies contradict each other and the lack of studies made on the correlation between dry-land muscle strength and endurance and middle distance swimming performance, this is an interesting subject to investigate further.

Aim

The aim of this study was to assess the correlation between bench press, pull-up and 400m freestyle swim performance in elite swimmers.

Research questions

What is the correlation between maximal strength in bench press and 400m swim performance in elite swimmers?
What is the correlation between muscle endurance in pull-up and 400m swim performance in elite swimmers?

Method

Subjects

In this study 15 swimmers (age 16-20) from Jönköping swim club were asked to participate and all agreed participation. They were recruited via their coach and email. One inclusion criteria for the study was competition at national or international level, which in this study was considered as elite swimmers. Other inclusion criteria were that they had to compete for Jönköping swim club and be between the ages of 16 to 20 years. They were excluded from the study if they had an injury or any health complications affecting their performance within the last four months or if they couldn’t participate in all tests.

Test procedures

The subjects performed three tests on three separate days, all test was performed in the morning. The subjects received information about how the test was going to be executed before each test.

Data such as age and gender were collected before the test on the first occasion. All subjects were instructed to bring the appropriate clothing and shoes to the test occasions. Subjects were recommended to not perform hard physical activity, consume alcohol, caffeine or energy drinks within 24 hours of each test occasion and to avoid eating a heavy meal within three to four hours before tests.

Bench press test

The maximal muscle strength tests performed in this study was a one repetition maximum (1RM) bench press test. The bench test was performed by using the 1RM testing protocol by Baechle & Earl (2008) (appendices 2). The protocol included a warmup of five to ten repetitions of the exercise followed by a rest period, five more repetitions and a rest period before an estimation of the subjects near-maximum load was made. The load was then increased successively until the subject could only perform one repetition of the exercise, the maximum load was recorded in kilograms and then used in the statistical analysis. In-between each step and load increase the subjects were given a rest period of two to four minutes. During the test a spotter assisted to make sure that the exercise was performed correctly and in a safe way. The execution of the exercise was performed according to the instructions given by Baechle & Earl (2008) (appendices 1). Before the test, the subjects performed five repetition of the exercise to become familiar with the execution, then rested for five minutes before starting the test protocol. In a non-laboratory situation, the 1RM test is considered the gold standard for assessing muscle strength and is a valid and reliable method for measuring maximal muscle strength (Lavinger et al., 2009).

Pull-up test

The pull-up test was chosen to assess the muscle endurance by performing as many pull-ups as possible during 30s. Before starting the test the subject were given information about the test, how to perform a correct pull-up as explained by Larsson, et.al. (2015). The subjects were instructed to hang from the bar with an overhand grip and hands shoulder width apart. While hanging they should not be able to touch the floor with their feet. To perform a pull-up, they started from a hanging position with their elbows fully extended then they pulled themselves up until their shin reached over the bar. They then lowered themselves until their elbows where fully extended again.

They were also instructed to keep their legs extended during the exercise and any in-correct performed pull-ups would not be counted. As a warmup, the subjects performed 300m freestyle swimming in a steady and easy pace in a 50m pool. The subjects got the opportunity to perform five repetitions of pull-ups before the test to practice and then rested for five minutes before starting the test. The 30s was timed using a handheld stopwatch (S141 Seiko, Tokyo, Japan) and the time started when the test leader counted down from three. When 30s had passed the test leader said "stop" and the number of correct and completed pull-ups were recorded and then used in the statistical analysis. Previously pull-ups have been used in a several studies to assess muscle strength and endurance by performing as many as possible with or without a time restriction (Negrete, Hanney, Kolber, Davies, Ansley, McBride, & Overstreet, 2010; Negrete, Hanney, Pabian, & Kolber, 2013; Lester, Sharp, Werling, Walker, Cohen, & Ruediger, 2014; Ozimek, Staszkiewicz, Rokowski, & Stanula, 2016; Larsson et al., 2015).

V4 speed test

A swimmer's aerobic capacity can be determined by performing 400m freestyle swimming at submaximal intensity and the higher swim speed performed by the swimmer at 4 mmol/l blood lactate the higher the swimmer's aerobic capacity is (Olbrecht et al., 1985). Therefore, a V4 speed test was chosen to measure swim performance.

The test was performed based on a protocol by Champam (2014) and in a 50m pool indoors. Before the test started the subjects were given instructions and information about the test and were then given a heart rate monitor (Cardio Swim Radio, Freelap, Fleurier, Switzerland) to put on. The subjects were instructed to warmup in the pool with a steady and easy pace doing 300m freestyle. After the warmup, the subjects rested for three minutes before starting the test. The subjects started in the water and then swam 400m. They were instructed to keep the speed as steady as possible while keeping the intensity high at 90% of maximum, and the goal was to have a blood lactate level as close to 4 mmol/l as possible after the race. The time was recorded over the covered distance by an electronic timing system (Relay Swim, Freelap, Fleurier, Switzerland). The Freelap timing system has an accuracy of 2/100 seconds (Freelap, 2017). A handheld stopwatch (S141 Seiko, Tokyo, Japan) was also used to record time and was then compared to the electronic timing system to make sure the time was accurate. With the handheld stopwatch time was also recorded every

100m make sure the subjects kept a steady speed, but this was not used in the final calculation. If they did not keep a steady speed the test leader let the swimmer know it during the test.

The subjects blood lactate (Lactate Scout+, EKF, Penarth, Wales) were taken one and three minutes after they finished, and the highest blood lactate level was recorded. If a subject's blood lactate levels were over 6 mmol/l their result was not included in the study since the calculation does not work for levels above 6 mmol/L. To calculate the V4 speed (appendices 3) the time recorded over covered distance was first converted in to seconds. Then the difference between the subject's blood lactate levels and the lactate threshold, 4 mmol/L, was calculated. This number where then multiplied by 10 and then multiplied by ether 0.1, 0.3, 0.5 or 0.4 depending on their recorded blood lactate. This number was then added to the time over covered distance if their lactate was over 4.0 mmol/L and was subtracted from the time if lactate was under 4.0 mmol/L. This result is the V4 speed and a lower number indicates a better performance. If their blood lactate was 4.0 mmol/L the V4 speed was the same as there total time. From this test V4 speed in seconds was used in the statistical analysis

This V4 speed test have been widely used within Jönköping swim club, therefore both the subjects and the coach where very familiar with the test. However, to the knowledge of the author in this present study this test protocol has not previously been used in other studies, but a similar test called the two-speed test have been used (Olbrecht et a., 1985; Rodriguez, 1994; Rodriguez et al., 2003). The two-speed test consist of two parts, one where the subjects perform a 400m swim at submaximal intensity, as in this present study, and then a 400m swim at maximal intensity. As in the present study the two-speed test also measured time over covered distance and lactate levels after the swim. The two-speed test have been considered one of the best tests for determining swim-specific aerobic endurance (Rodríguez, 1994).

Ethical and social considerations

Before the start of this study all subjects received verbal and written information about the study including the method, aim and the criteria for participating. They were also informed that they at any time could decide to terminate their participation, that it was voluntary to participate and the risks and benefits associated with the study. Everyone got the opportunity to ask questions and received the information of where to turn for any further question. A written information was given to the subjects, along with an informed consent that they signed and where given a copy of. The ethical principles of this study were based on the Declaration of Helsinki (World Medical Association, 2013). The results of this study may be used by athletes and coaches when designing training programs for swimmers, it can help swimmers to improve their swim performance. It may give an idea of whether to put more emphasis on maximal muscle strength or muscle endurance when planning a training program to improve swim performance. The results can also provide information and a foundation for further studies on the subject and possible a new protocol to measure swim performance.

Statistics

This study was a correlation study and the data collected during the study was analyzed in SPSS (IBM SPSS version 24, Chicago, IL, USA). To determine if the data was normally distributed the Shapiro-Wilks test ($p=\geq 0.05$) was used and to calculate the correlation between the variables the Pearson's test was used since the data was normally distributed, data is presented with mean and standard deviation (±SD). The correlation was classified as follows: <0.2 = very weak correlation, 0.2 - 0.4 = weak correlation, 0.4 - 0.6 = moderate correlation, 0.6 - 0.8 = strong correlation, >0.8 very strong correlation (Keiner, Yaghobi, Sander, Wirth, & Hartmann, 2015).

Results

This study investigated the relationship between freestyle swim performance and upper body strength and endurance. Fifteen subjects attended the first test, two did not perform all tests and where therefor excluded from this study. The subjects consisted of four women and nine men age 16-20 years and their descriptive data are shown in table 1 (n=13). The subjects results from the V4 speed test was 292.05(±16.07) s, repetitions of pull-up was 10.62(±7.00), and in the bench press the results was 67.08(±20.30) kg.

Table 1: The table shows the subjects age and results of the V4 speed, Pull-up-, and Bench press tests presented as mean(SD) for the hole group and for men and women separately.

	All subjects (n=13)	Women (n=4)	Men (n=9)

Age	18 (±1.15)	18 (±1.41)	18 (±1.11)
V4 Speed (s)	291.05 (±16.07)	305.5(±12.34)	284.63(±11.94)
Pull-up (reps*)	10.62 (±7.00)	2.00(±1.22)	14.44(±4.11)
Bench press (kg)	67.08 (±20.30)	43.00 (±3.08)	77.78(±13.15)

*reps (repetitions)

Strength and endurance were negatively associated to swim performance; the higher values in strength and endurance the better swim performance. There was a moderate negative correlation between bench press and swim performance (V4 speed) (r=-0.54, p=0.06) and a strong negative correlation between pull-ups and swim performance (V4 speed) (r=-0.63, p=0.02). For bench press, r^2 was 0.29 indicating that maximal muscle strength explained 29% of the swim performance. For pull-ups, the r^2 was 0.39 indicating that muscle endurance explained 39% of the swim performance (table 2).

Table 2: The relationship of swim performance (V4 speed) with pull-ups and bench press, presented as correlation coefficients, coefficient of determination, and p-value, (n=13).

	Correlation coefficients (r)	Coefficient of determination (r^2)	P-value (p)
Bench press (kg)	-0.54	0.29	0.06
Pull-up (reps*)	-0.63	0.39	0.02

*repetitions

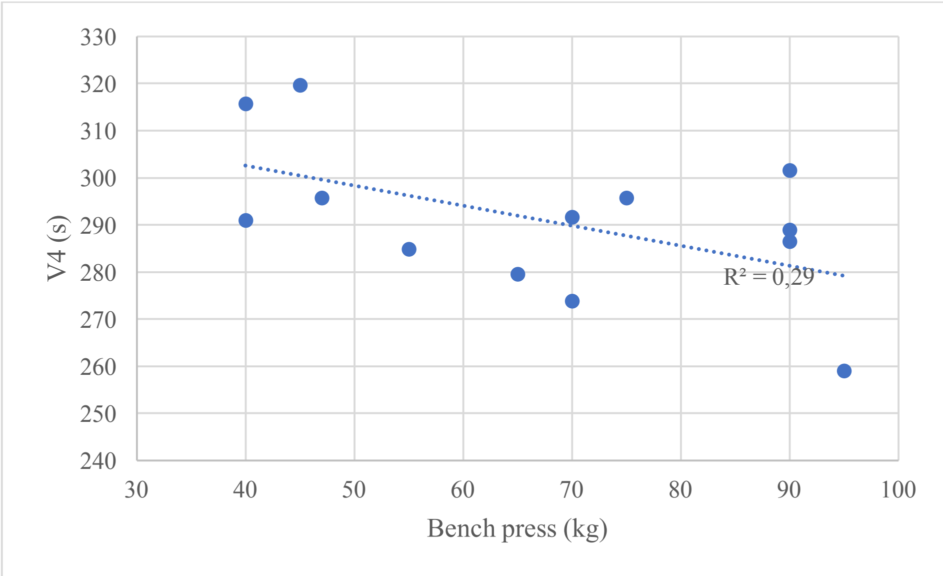

Figure 1: The figure shows the linear correlation (r=-0.54) between swim performance of V4 speed test presented in seconds and on repetition maximum in bench press and the coefficient of determination (r^2=0.29) in elite swimmers (n=13), p=0.06.

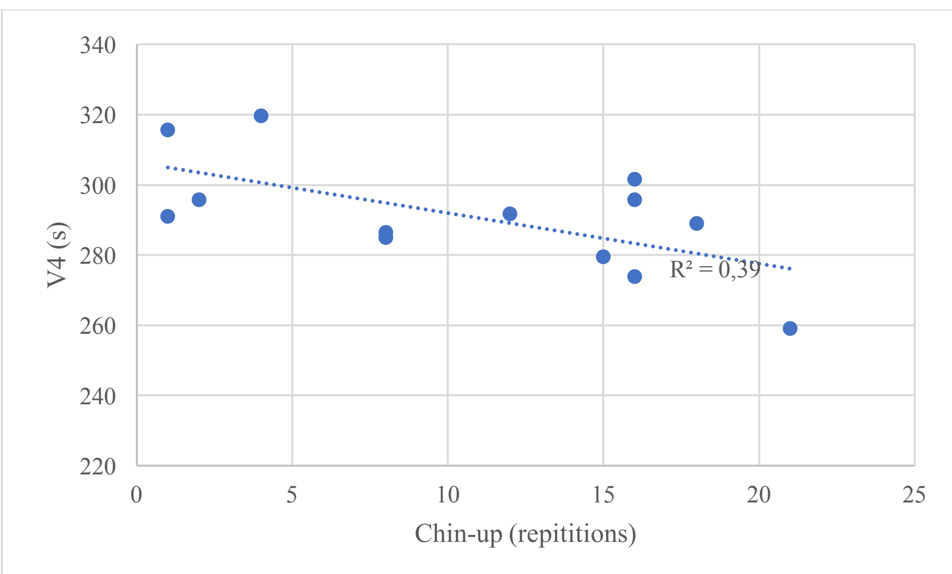

Figure 2: The figure shows the linear correlation (r=-0.63) between swim performance of V4 speed test presented in seconds and nuber of repititions of pull-up durring 30 secounds and the coefficient of detarmination (r^2=0.39) in elite swimmers (n=13), p=0.02.

Discussion

The aim of this study was to assess the relationship between upper body muscle strength and endurance with 400m freestyle swim performance in elite swimmers. The result shows a moderate correlation between muscle strength measured as 1RM in bench press and swim performance measured as V4 speed. There was a strong correlation between muscle endurance measured as number of repetitions of pull-ups during 30 seconds and swim performance measured as V4 speed.

Result discussion

In this study, the relationship between muscle strength in bench press had a moderate correlation to 400m distance freestyle swim performance at r=-0.54. Previous studies have showen similar results or stronger correlations when studying the relationship between muscle strength in bench press and swim performance (Garrido et al., 2010; Keiner et al., 2015). Garrido et al. (2010) showed r=-0.57 (25m) and r=-0.59 (50m), Keiner et al. (2015) showed r=-0.84 (15m), r=-0.85 (25m), r=-0.83 (50m) and r=-0.81 (100m). These studies all measured maximal muscle strength during the bench press as did the present study. However, the measurement for the swim test varied, Garrido et al. (2010) and Keiner et al. (2015) used time over covered distance to determine swim performance whilst this present study used time over covered distance and blood lactate to determine swim performance. As in this study Garrido et al. (2010) and Keiner et al. (2015) also used subjects at younger ages between 12 and 19 years. The swim distances used in those studies was significantly shorter, 15 to 100m, than the distance used in this present study, 400m.

A study by Morouço et al. (2011) also showed a similar correlation between muscle strength in bench press and swim performance, ranging between r=0.6 and r=0.7. However, the methods where different compared to the present study and the studies by Garrido et al. (2010) and Keiner et al. (2015). Morouço et al. (2011) used the mean propulsive power to measure muscle strength in bench press and used mean force production during a 30s-maximal effort tethered swimming and swimming velocity to measure swim performance. The present study and the studies by Garrido et al. (2010), Keiner et al. (2015) and Morouço et al. (2011), despite different methods, showed a moderate or strong correlation between muscle strength in bench press and swim performance.

One study by Sandhu et al. (2012) showed a very weak correlation between muscle strength in bench press and swim performance at r=0.0018 (50m) and r=0.081 (300m). Sandhu et.al. (2012) also used maximal strength as a measurement in bench press and time over covered distance to measure swim performance. In this study both a shorter distance like in the studies by Garrido et al. (2010), Keiner et al. (2015) and Morouço et al. (2011) was measured along with a longer distance like the present study. Howerver, the subjects used by Sandhu et al. (2012) differed from the other studies by using a significantly higher number (n=60) of subjects and a wider age range (age=16-35). The differences in the populations and results may indicate that muscle strength in bench press is more important for younger swimmers, but further studies are needed for a conclusion to be drawn.

The second relationship assessed in the present study was between muscle endurance measured as number of repetitions of pull-ups during 30s and 400m swim performance measured as V4 speed. The results showed a strong correlation at r=-0.63. Previous studies using pull-ups to measure muscle endurance and it´s correlation to swim performance have not been found, but one study using lat-pulldown to measure muscle strength was found (Morouço et al., 2011). Pull-ups and lat-pulldown are both exercises for the back muscles, no study was found that showed they were interchangeable. However, both may be able to measure muscle endurance depending on the method used. Morouço et al. (2011) measured muscle strength as mean propulsive power of the lat-pulldown and the swim performance was measured as mean force production during a 30s maximal effort tethers swimming and swimming velocity. The results showed a correlation between r=0.65 and r=0.69, a result similar to the one in the present study at r=-0.63. The methods used in the present study and in the studied by Morouço et al. (2011) were different but the results may indicate the importance of back muscle strength and endurance to swim performance, but more studies are needed on this subject.

This present study showed a higher correlation between pull-ups and swim performance compared to the correlation between bench press and swim performance. This may be because pull-ups are more sport specific and more similar to the movements during freestyle swimming than bench press is. The pull-up test was testing muscle endurance whilst the bench press was testing maximal muscle strength and may also be the reason for the difference in correlations. This difference shows that muscle endurance of the back muscles is stronger correlated with 400m swim performance than the maximal strength of the chest muscles. This may also indicate that more muscle endurance exercises should be incorporated in to a training program to improve 400m swim performance. It could also indicate that training back muscles may improve 400m swim performance more than training chest muscles. However, more studies examining this needs to be conducted to with more certainty be able to give any recommendations.

Method discussion

This present study included 13 subjects, do to the small number of subjects in this study, the data was only analyzed as one group and not women and men individually. This may also affect the results, since there could be differences between the genders (Baechle & Earle, 2008; McArdle et al., 2015). A larger number of subjects would allow correlations to be made for women and men as separated groups. The bench press and pull-up was chosen as the exercises for the muscle strength and endurance tests since m. Pectoralis major and m. Latissimus dorsi are considered important muscles in swimming (Lomax et al., 2015). Bench press was chosen to evaluate the maximal muscle strength of m. Pectoralis major and pull-up was chosen to evaluate the muscle endurance of m. Latissimus dorsi. The data recorded from these tests was not relative to the subject's body weight, which may be a source of error. Calculating the data relative to body weight may decrees the differences between genders (Baechle & Earle, 2008).

The swim test that was performed in this study was a V4 swim test, to the knowledge of this study's author the protocol has not previously been used in any studies. Therefor this specific protocol has not been tested for validity. A similar test that have been used before is the "two-speed test" (Olbrecht et al., 1985; Rodriguez, 1994; Rodriguez et al., 2003). The "two-speed test" is a two part test where the subjects first performs 400-meter swimming at submaximal intensity. The subject's rests for 20 minutes and then performs the second part, 400-meters swim at maximal intensity. Time over covered distance was recorded for both parts and blood lactate was also measured after 1, 3, 5 and 7 minutes of each 400-meter (Olbrecht et al., 1985) similar to the protocol in the present study, but it needs to be validated.

Furthermore, the choice of strength exercise and swim style, freestyle, may be a source of error since some subjects may be more comfortable and used to the once that was chosen than other subjects. The distance of the swim test, 400m, may also be a source of error since some subjects competed at shorter distances whiles some competed at 400m or more.

Conclusions

In conclusion, this study showed a moderate to strong correlation between bench press and pull-up with swim performance. The correlation between one repetition maximum in bench press and 400-meter freestyle swim performance was moderate. The correlation between number of pull-up repetitions during 30 seconds and 400-meter freestyle swim performance was strong. These results suggest that upper body strength contributes to swim performance over 400-meters. The stronger correlation between pull-ups and swimming indicated that muscle endurance of m. Latissimus dorsi and the back muscles may be important to incorporate in a training program since it has shown to have a strong correlation to swim performance at 400-meters.

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Appendices

Appendices 1 – Bench press execution with spotter

Starting position: Athlete

- Lie in a supine position on a bench in the five-point body contact position.
- Place the body on the bench so that the eyes are below the raced bar.
- Grasp the bar with a closed, pronated grip slightly wider than shoulder-width apart.
- Signal the spotter for assistance in moving the bar of the supports.
- Position the bar over the chest with the elbows fully extended.
- All repetitions begin from this position.

Starting position: Spotter

- Stand erect and very close to the head of the bench (but do not distract the athlete).
- Place the feet shoulder-width apart with the knees slightly flexed.
- Grasp the bar with a closed, alternated grip inside the athlete´s hands.
- At athlete´s signal, assist with moving the bar off the supports.
- Guide the bar to a position over the athlete´s chest.
- Release the bar smoothly.

Downward movement phase: Athlete

- Lower the bar to touch the chest at approximately nipple level.
- Keep the wrists stiff and the forearms perpendicular to the floor and parallel to each other.
- Maintain the five-point body contact position.

Downward movement phase: Spooter

- Keep the hands in the alternated grip position clos to—but not touching—the bar as it descends.
- Slightly flex the knees, hips, and torso and keep the back flat when following the bar.

Upward movement phase: Athlete

- Push the bar upward until the elbows are fully extended.
- Keep the wrists stiff and the forearms perpendicular to the floor and parallel to each other.
- Maintain the five-point body contact position.
- Do not arch the back or raise the chest to meet the bar.

- At the end of the set, signal the spotter for assistance in racking the bar.
- Keep a grip on the bar until it is racked.

Upward movement phase: Spotter

- Keep the hands in the alternated frip position close to—but not touching—the bar as it ascends.
- Slightly extend the knees, hips, and torso and keep the back flat when following the bar.
- At the athlete´s signal, grasp the bar with an alternated grip inside the athlete´s hands.
- Guide the bar back onto the supports.
- Keep a grip on the bar until it is racked.

(Baechle & Earle, 2008)

Appendices 2 – 1RM Bench press protocol

1. Instruct the athlete to warm up with a light resistance that easily allows 5 to 10 repetitions.
2. Provide a 1-minute rest period.
3. Estimate a warm-up load that will allow the athlete to complete three to five repetitions by adding
    a. 10 to 20 pounds (4-9 kg) or 5% to 10% for upper body exercise or
    b. 30 to 40 pounds (14-18 kg) or 10% to 20% for lower body exercises.
4. Provide a 2-minute rest period.
5. Estimate a conservative, near-maximal load that will allow the athlete to complete two to three repetitions by adding
    a. 10 to 20 pounds (4-9 kg) or 5% to 10% for upper body exercise or
    b. 30 to 40 pounds (14-18 kg) or 10% to 20% for lower body exercises.
6. Provide a 2- to 4-minute rest period.
7. Make a load increase:
    a. 10 to 20 pounds (4-9 kg) or 5% to 10% for upper body exercise or
    b. 30 to 40 pounds (14-18 kg) or 10% to 20% for lower body exercises.
8. Instruct the athlete to attempt a 1RM.
9. If the athlete was successful, provide a 2- to 4-minute rest period and go back to step 7.
10. If the athlete failed, provide 2- to 4-minute rest period, then decrease the load by subtracting
    a. 5 to 10 pounds (2-4 kg) or 2.5% to 15% for upper body exercise or
    b. 15 to 20 pounds (7-9 kg) or 5% to 10% for lower body exercises.
11. And then go back to step 8.
12. Continue increasing or decreasing the load until the athlete can complete one repetition with proper exercise technique. Ideally, the athlete´s 1RM will be measured within three to five testing sets.

(Baechle & Earle, 2008)

Appendices 3 – V4 speed calculation

Lactate	+/- in calculation	Seconds/0.1 mmol/L lactate
5.1 – 6.0 mmol/L	+	0.1
4.1 – 5.0 mmol/L	+	0.3
4.0 mmol/L	No change	
3.0 – 3.9 mmol/L	-	0.5
2.0 – 2.9 mmol/L	-	0.4

Calculation: total time ± ((lactate diff* x 10) x seconds according to table) = V4 Speed

* The difference between blood lactate measured after the test and 4.0 mmol/L

K.J. Gårdström (Personal Communication, 1 May, 2017)

Appendices 4 – Informed consent

Information till deltagare i studien "Vad påverkar sim prestationen hos elitsimmare?"

Bakgrund

Vi är två studenter från Högskolan i Halmstad som läser Biomedicin med inriktning fysisk träning, där ovanstående studie kommer att bli våra examensarbeten. Studien innehåller två olika delar:

Studiens första del

Flera studier har visat att prestation inom simning kan förbättrats med hjälp av aktiveringsövningar. Aktiveringsövningar innebär att styrkeövningar utförs precis innan en prestation som exempelvis ett sim lopp. Denna metod har bara studerats några få gånger i sporten simning. De flesta av dessa studier är utförda på underkroppen och övre delen av ryggen och med tunga vikter. Baksidan av överarmen och ryggen har visat sig ha stor betydelse för prestationen inom simning. Syftet med studiens första del är därför att utvärdera om aktiveringsövning med gummiband för baksidan av överarmen och ryggen innan ett 400-meter maximalt frisims lopp kan förbättra prestationen hos en elitsimmare.

Studiens andra del

Tidigare har ett antal studier visat att ett utfört styrketräningsprogram kan förbättra prestationen i simning. Det har däremot inte gjorts lika många studier på sambandet mellan maximal muskelstyrka och prestation i simning. De fåtal studier som undersökt detta har visat på ett svagt till medelstarkt samband. De studier som undersökt styrketräningsprogram och de som undersökt maximal muskelstyrka har inte visat på samma resultat. På grund av detta och det bristande antalet liknande studier som gjorts är syftet för denna studie att undersöka sambandet mellan styrka i bänkpress och pull-ups med prestationen i 400 meter frisim hos elitsimmare.

Förfrågan om deltagande

I denna studie kommer elitsimmare från Jönköpings simklubb att tillfrågas om deltagande. Vi har fått tillgång till ditt namn från en lag lista som coacherna i Jönköpings simklubb har skickat. Vi undrar därför om du har möjlighet att delta i denna studie då du är en av dessa.

Hur går studien till?

Du ombeds att delta under fyra tillfällen med tre dagars mellanrum. Första tillfället kommer bestå av ett 400 meters sim test. Efter detta sim test kommer du utföra ett maximalt styrketest för att ta reda på vilket motstånd på gummibandet du ska använda till aktiveringsövningen. Detta görs genom att successivt öka motstånd tills du precis kan göra 10 repetitioner av övningen. Det andra tillfället kommer att bestå av en aktiveringsövning och ett 400 meters sim test. Under detta testtillfället kommer du utföra en aktiveringsövning med gummiband för baksidan av övre armen och ryggen, som efterliknar ett simtag. Därefter vilar du i 6 minuter och utför sedan ett likadant 400 meter sim test som vid första tillfället. Båda sim testerna kommer att vara ett 400 meters fristils lopp och kommer att mätas med tid och mjölksyramätning. Vid det tredje tillfället kommer du att utföra ett maximalt styrketest i bänkpress och fjärde testtillfället kommer du att utföra ett styrketest i pull-ups.

Vilka är riskerna?

På grund av de maximala insatserna som krävs av dig i denna studie förekommer en viss risk för skada. Två testledare kommer att vara närvarande vid alla testtillfällen och noga instruera och säkerställa att testerna utförs korrekt för att minska risken för skador. Det är också viktigt att du är skadefri, frisk och gjort en ordentlig uppvärmning för att inte förvärra ett tillstånd genom deltagande. Risk för upplevt obehag kan även förekomma då blodprov kommer tas med ett stick i fingret vid båda sim testerna.

Finns det några fördelar?

Genom att delta i denna studie kommer du få veta ditt en repetition maximum i bänkpress och antal repetitioner av pull-ups under 30 sekunder. Du kommer få kunskap om hur överkroppsstyrka påverkar prestation i simning, även om en aktiveringsövning kan förbättra prestationen i simning.

Hantering av data och sekretess

Huvudman för studien är Högskolan i Halmstad. Den data som samlas in i studien kommer endast att hanteras av testledarna. Dina resultat kommer att behandlas så att inga obehöriga kan ta del av dem. Datan kommer att förvaras på ett USB-minne som efter studien kommer att förvaras på Högskolan i Halmstad. Ditt deltagande i studien kommer vara konfidentiellt vilket innebär att ditt namn kommer att ersättas med ett löpnummer. Efter avslutad studie har du rätt att ta del av dina resultat. En sammanställning kommer att göras av resultaten från testerna, dessa kommer endast att presenteras på gruppnivå.

Hur får jag information om studiens resultat

För att ta del av dina resultat från denna studie kan du kontakta Madeleine Eriksson och Natalie Storck, kontaktinformation finns nedan. Det slutliga resultatet i studien kommer sedan att publiceras i en C-uppsats på portalen Diva.

Frivillighet

Deltagandet i denna studien är frivilligt och som försöksperson har du rätten att avbryta ditt deltagande när som helst under studiens gång utan att ange någon orsak. Om du väljer att avbryta ditt deltagande kontaktar du Madeleine Eriksson eller Natalie Storck, kontaktinformation finns nedan. Vid avbrutet deltagande kommer, om så önskas, den insamlade datan att förstöras och den kommer inte att användas i studien.

Ansvariga

Forskningshuvudman för denna studie är Högskolan i Halmstad och huvudansvariga forskare i är Madeleine Eriksson och Natalie Storck. Du kan även kontakta dem för ytterligare information om studien eller eventuella frågor.

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