

STRENGTH ABILITIES IN SPORTS SWIMMING A SYSTEMATIC REVIEW**Jarosław Nadobnik, Aleksander Wiażewicz**

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Review paper

Abstract

Strength training is an important part of the preparation of competitive athletes. The subject of interest of the scientists connected of sports swimming was the level of strength ability of the competitors practising this sport and the influence of this ability on the final sports result. The purpose of this review is to describe and consider the impact of strength training of the shoulder muscles in sports swimming. A literature review was conducted in Embase, Medline PubMed, DOAJ, EBSCO and Google databases. Basic search terms are: training in sports swimming, strength tests, evaluation of muscle properties, rotation of the arm, strength measurement methods. Results: 235 results were found and 148 professional publications were selected and analysed. A thorough review of scientific publications indicates that strength parameters of the shoulder girdle muscles played a very important role on the sports performance of swimmers. The programmes combining swim training with 'on land' strength improvement or electrical stimulation are more effective than swim training alone. Significant fatigue of the rotator muscles can impair shoulder stability and result in injury. Increased strength in the internal rotation movement may result pathological conditions of the shoulder.

Keywords: *Training, swimming, muscles, strength tests, strength ability*

Introduction

The sport of swimming undergoes constant and intensive development (Stachura et al., 2011). A detailed analysis of the results in sport swimming indicates their continuous and dynamic progress and, consequently, the development of the discipline (Bartkowiak, 1999). The ultimate goal of sports swimming is to cover a set distance in a minimum time (Maglischo, 2003; Toussaint, 2007). The achievement of this goal is determined by the level of technical, strength, coordination and energy properties of the swimmer's body (Lach and Rolski, 1996; Łubkowska et al., 2017). In the selection and selection process for high level sport swimming, athletes with specific pre-dispositions are sought (Bartkowiak, 1997; Czabański et al., 2003). Due to the multitude and complexity of these elements, the necessity to take into account a complex of traits is emphasised (Czabański et al., 2003). The subject of interest of scientists connected with sports swimming is the level of strength abilities of the competitors practicing this sport and the influence of strength abilities on the final sports result. Laboratory measurements of biomechanical muscle properties, land tests (static and dynamic), tethered swimming tests and isokinetic tests using state-of-the-art dynamometers are used for their assessment.

The swimming is one of the most demanding sports. Training sessions are usually 5 to 7 days a week,

often twice a day. Considering a full calendar year, the average daily training volume is between 6 000 m and 10 000 m. This corresponds to approximately 60 000 m to 80 000 m of total swimming distance per week (Richardson et al., 1980; Beach et al., 1992). Assuming an average number of arm strokes of 8 to 10 over a distance of 25m, athletes perform 30,000 rotations of each shoulder joint per week, which puts enormous stress on the shoulder girdle (Heinlein and Cosgarea, 2010). This is also corroborated by Bak (1996), who describes top level swim training of 20 to 30 hours per week, resulting in an average of 500,000 shoulder movements for a professional athlete per year (Bak, 1996). Other authors (McMaster, 1999; Johnson et al., 2003) state that this can be over 1 million times per annual cycle. In addition, the time spent by the athlete on land training must be taken into account. Platonov (1997) states that this is between 250 and 350 hours per year. Long-term, rational, but also intensive training is able to ensure that the athlete reaches a high sporting level. The best athletes have a training length of 10 to 12 years (Bartkowiak, 1999). High-level sport swimming requires certain predispositions. One of them is the somatic build - genetically conditioned. Athletes with a suitable body build are sought after (Bartkowiak, 1997; Czabański et al., 2003). Selection should be based on stable factors such as: body proportions, height and lean body mass, smooth musculature, fine bone structure,

length and width of hands and feet, comparison of calendar and bio-logical age, level of motor coordination and vital capacity of the lungs, or measurement of the range of motion in the shoulder and ankle joints (Butowicz, 1965; Bartkowiak, 1997; Chomiak and Migasiewicz, 1998; Jaszczanin, 1999; Czabański et al, 2003; Maszczyk et al, 2011), rather than on traits that are temporal in nature - e.g. speed of learning swimming movements (Bartkowiak, 1997; Czabanski et al, 2003). In addition to talent, Chomiak and Migasiewicz (1998) mention interest in discipline, diligence and good health. Proper selection ensures the identification of sports talents and their further effective development. When the motor abilities and potential of young athletes are at a similar level, one should look for characteristics that will give an advantage over others.

For swimmers these are: height and body mass, length and width of feet and hands, length of up-per and lower limbs, chest circumference, arm span. The increased surface area of certain body parts allows for increased propulsive forces, which naturally results in gaining an advantage (Chomiak and Migasiewicz, 1998; Geladas et al, 2005; Zampagni et al, 2008; Barghamadi and Behboodi, 2010).

Methods

A articles and reference texts review was con-ducted using electronic databases such as Embase, Medline PubMed, DOAJ, EBSCO and Google databases. The authors began qualifying articles for review based on titles and abstracts after obtaining files containing all searches from data-bases. Inclusion and exclusion criteria were specified for the analysis of titles, abstracts and full texts. Basic search terms are: training in sports swimming, strength tests, evaluation of muscle properties, rotation of the arm, strength measurement methods, 235 publications found in total, were selected and analysed 148 professional publications.

Results

Some authors (Baturó et al, 1984; Hawley and Williams, 1991; Toussaint, 2007) state that a high score in sports swimming is determined by the athlete's ability to maintain a high swimming speed for a certain period of time. The basic criterion for assessing the swimming performance of athletes involved in sport swimming is the aver-age swimming speed over the crown distance in relation to their maximum swimming speed (Bartkowiak, 1999). The above-described ability to maintain high swimming speed depends largely on muscular endurance, general fitness, correct technique and energy expenditure (Baturó et al., 1984).

It is described that the result in sports swimming depends on: the degree of mastery of technique, specific muscle strength, high aerobic capacity and specific endurance. General fitness is also mentioned

(Bartkowiak, 1999). Only proportional development of all parameters of a swimmer: optimal level of strength, power endurance, aerobic and anaerobic energy delivery mechanisms, cycle length, swimming speed, technique and coordination can ensure the achievement of a high sporting level (Pansold et al., 1982).

When certain predispositions are a barrier to achieving higher swimming speeds, it is proposed to exploit the individual potential inherent in other properties of the swimmer's body (technical, strength, coordination, aerobic or anaerobic endurance) (Lach and Rolski, 1996; Łubkowska et al., 2017).

Motor skills affecting swimming performance

Strength, speed and endurance are mentioned as the motor abilities with the greatest influence on performance in sports swimming (Bartkowiak, 1999; Banach et al., 2015). Additionally, Platonov (1997) considers flexibility and motor coordination as equally important. Ultimately, however, authors involved in the analysis of swimming performance (Baturó et al, 1984; Bartkowiak, 1999; Morais et al, 2016) include competitive swimming among disciplines in which the level of strength is largely responsible for the final result. A swimmer's strength capabilities are manifested in the form of propulsive force, also known as "thrust force". Its magnitude depends on body mass, somatic build and the degree of mastery of technique. It also emphasises the constant need to observe the size and dynamics of changes in this motor ability. In addition, strength in swimmers should be developed in proportion to speed and endurance, taking into account the correct technique.

Specifics of strength training in sports swimming

Strength preparation is a very important component that contributes to the final outcome during sport swimming (Crowe et al, 1999; Dopsaj et al, 2004; Kalczyński et al, 2005; Kjendlie and Thorsvald, 2006; Girold et al, 2007; Aspenes et al. , 2009; Garrido et al, 2010a, 2010b; Morouço et al, 2011b, 2011c; Łubkowska et al, 2017), provided the specificity of swim training (Tanaka et al, 1993) and economic technique (Platonov, 1997; Barbosa et al, 2010) are taken into account. Strength preparation, is of particular importance during short-distance competitions, in relation to technical preparation (Wilkei and Madsen, 1986; Swaine, 2000; Stager and Coyle, 2005; Morouço et al, 2011a). However, strength has also been identified as one of the main factors that can increase swimming speed, not only in sprinting competitions (Toussaint, 2007; Lubkowska et al., 2017), but also in middle distances (Hawley and Williams, 1991; Belfry et al., 2016). Different types of strength are reported to determine success at different distances. Maximal strength and breaka-way strength significantly influence speed

ability, thrust, and the characteristics of the starting jump and recurve important factors influencing performance in 50m, 100m and 200m swimming. On the other hand, strength endurance has the greatest influence on the results achieved in the 800 m and 1500 m distances (Platonov, 1997). Strength training takes up more than half of the time allocated to "land training" (Platonov, 1997) and is a common practice in swim training.

It should take into account the dynamic nature of movements during movement in water. For this reason, speed and power exercises are proposed to shape relative strength (Platonov, 1997; Aspenes et al, 2009, Garrido et al, 2010a; Morouço et al, 2012). In addition, the development of strength endurance is proposed (Platonov, 1997). The following methods of muscle strength development should be used in the training of swimmers: isometric, isotonic, isokinetic and variable resistance. Speed and power exercises should be performed at a high speed (80-100% of maximum speed), with a high load (70-90% of maximum weight), in a small number of repetitions (1-10). It is then possible to observe the increase of the breaking and maximum strength. Endurance and power exercises should be performed at the swimming pace of the crown distance, with a medium load (45-80% of the maximum weight), in a considerable number of repetitions (20-200) (Platonov, 1997).

It should be borne in mind that an increase in body mass and an increase in frontal resistance induced by training aimed at the expansion of muscle mass could cause adverse changes that slow the swimmer down (Żurawik and Karpiński, 1996; Platonow, 1997; Bartkowiak 1999, Newton et al, 2002).

It is reported that strength exercises should mainly target the muscles of the upper limbs, lower limbs, shoulder girdle and back. But special care should be taken when dosing loads for young athletes (Batkowiak, 1999). The selected strength exercises should be consistent in all parameters (pace, form, structure) with the movements associated with swimming the crown distance, with targeted and special exercises - e.g. exercises imitating strokes in a given style (Platonov, 1997; Maglischo, 2003).

Platonov (1985, 1997) describe the occurrence of muscle strength dependence, with the use of strength abilities during swimming. The first stage - the phase of reduced abilities, occurs in the period of 4-6 weeks after the initiation of training of strength abilities. Thanks to comprehensive and targeted measures, the level of strength increases, while the level of coordination decreases and the flexibility of muscles and ligaments deteriorates. There is a decrease in the speed of movement in water, a decrease in the level of thrust, strength endurance and power. The second stage - the adjustment phase, lasts another 3-4 weeks and consists in the

beginning of using the strength abilities during swimming. The dynamics and kinematics of movements are improved. The third stage, the phase of parallel development, consists in linking strength abilities with technical and coordination abilities. The level of thrust and power increases.

It should be taken into account that the effectiveness of strength training of swimmers depends on many factors. For example, genetic predisposition (Grenda et al., 2015), training methodology, or non-training factors: post-workout recovery or nutrition (Łubkowska et al., 2014).

Muscle power during rowing movements

Putting or keeping the body in motion is determined by the presence of force, caused by the rowing movements of the upper limbs, lower limbs and trunk. Through the interaction of the limbs and trunk, propulsive force is generated (Baturó et al, 1984; Kalinowski & Roszko, 1986; Bartkowiak, 1999; Jaszczanin, 1999; Czabański et al, 2003; Przybylska, 2010). Propulsive force is the result of the interaction between the swimmer's limbs and the water environment (it is the reaction of water resistance to limb movement) (Baturó et al, 1984). The efficiency of the movement is based on the speed of movement of the limbs during the actual phase. It should be greater than the speed of the athlete's body during swimming.

This is the condition for the creation of a forward acceleration (Bogajewski et al., 1969; Bartkowiak, 1999). The speed at which a swimmer moves in water mainly depends on the propulsive force, which is a determinant of the efficiency of the athlete's movement (Toussaint and Vervoorn, 1990; Hawley and Williams, 1991; Tanaka and Swensen, 1998; Jaszczanin, 1999; Aspenes et al, 2009). However, Morouço et al (2014) report that the relationship between swimming speed and maximum force can be non-linear, while a linear relationship occurs with maximum force impulse. However, when competing at a championship level, it can be conjectured that it is the value of propulsive forces that is a significant factor influencing the athlete's final performance (Baturó et al., 1984). It is contingent upon the achievement of a high sporting performance to maximise the ability to generate propulsive forces and minimise the resistance generated by the aquatic environment (Vilas-Boas et al., 2010).

Upper and lower limb maximal force parameters and trunk maximal force are good predictors of sprint race performance among young swimmers (Keiner et al., 2015). However, it is the cyclic movements of the upper limbs that are the main drive during swimming. They constitute (according to different authors): the primary propulsive force, in the kraul (Richardson, 1983; Hollander et al, 1988; Toussaint and Beek, 1992; Troszczyński, 1999; Przybylska, 2010); about 65% of the swimming speed in

backstroke and butterfly (Dybinska, 2011); about 70-80% (Bartkowiak, 1984, 1999); or almost 90% of the overall propulsion force (Pink and Tibone, 2000); and up to 80% of the propulsion force in kraulic sprint events, and up to 100% in longdistance events (Przybylska, 2010).

The results presented by some authors (Absaliyev, 1955; Morouço et al., 2011a,) obtained in athletes when swimming with the upper limbs alone are better than when swimming with the legs alone. In contrast, Bogajewski et al (1969) believe that the relationship between upper and lower limb performance is difficult to determine. Hawley et al (1992) found that increasing leg muscle strength does not increase 50 m swimming speed. Swaine et al. (2010) and Morouço et al. (2015) report that the value of the force produced during kite swimming, depends on the work of the lower limbs to a much greater extent than reported by other authors. And they confirm that, in some cases, the power obtained through the work of the lower limbs is greater than that of the upper limbs (Swaine, 2000). Other authors (Bartkowiak, 1984; Laughlin, 2007; Montgomery and Chambers, 2009) report that lower limb work is as important as upper limb work even though the legs do not provide as much propulsion.

During swim training, attention should not be given solely to the upper limbs, neglecting the role of the lower limbs (Loturco et al., 2016), or body movements and their importance for coordination (Morouço et al., 2012). Additionally, there is a need to separately assess upper and lower limb muscle strength characteristics at regular intervals and to incorporate these measures into training design (Nikolaidis, 2012).

Despite the above discussions, most researchers and trainers tend to agree with Toussaint and Beek (1992), who state that the main power generated during movement in water comes almost entirely from the work of the upper limbs and trunk. The authors (Baturó et al, 1984; Bartkowiak, 1999; Czabański et al, 2003) compare the swimmer's arm to a lever, for which the axis of rotation is the shoulder joint. They also emphasise the importance of arm length in achieving the desired strength. The rowing movement of the upper limbs is based on the use of maximum water resistance reactions at appropriate moments of movement. Force accuracy is one of the fundamental abilities that determine the effective and economical performance of any physical activity (Starosta, 2012). Consequently, optimal levels of strength and power are required for effective swimming as it is related to high propulsive force generation capacity (Newton et al., 2002; Vilas-Boas et al., 2010).

The high correlation of upper limb strength and power levels with swimming speed is highlighted (Toussaint and Vervoorn, 1990; Hawley and

Williams, 1991; Tanaka and Swensen, 1998; Aspenes et al, 2009). Despite the differences in researchers' views that exist, it is believed that improvements in upper limb strength can result in greater maximal strength when pulling the arm through the water and subsequently greater swimming speed, particularly in sprint competitions (Morouço et al., 2011a) but also over longer distances (Hawley and Williams, 1991).

Musculoskeletal complaints of the shoulder joint in competitive swimmers

According to many sources, shoulder injury is the most common complaint of competitive swimming athletes (McMaster, 1999; Weldon and Richardson, 2001; Mountjoy et al, 2010; Walker et al, 2012; de Almeida et al, 2015). Several areas of training practice (both in water and on land) were identified that may have put swimmers at risk of injury. These include: frequent use of lower limb alone work exercises with prolonged, incorrect upper limb positioning; excessive training volume; and use of stretching and strengthening exercises not in line with recent, current recommendations (Tate et al., 2015). A study by de Almeida et al (2015) found that approximately 60% of athletes reported at least one musculoskeletal complaint in the past 12 months. During top-level national competitions, the prevalence of pain was around 20%. Richardson et al (1980) found a prevalence of shoulder pain in 52% of swimmers representing very high levels of sport and in 27% of swimmers at lower levels. McMaster and Troup (1993) described shoulder joint complaints occurring in 47% of swimmers aged between 10 and 18 years, in 66% of older swimmers and among 73% of swimmers representing high sport levels who reported pain in this area. Hellard et al (2015) re-port that the frequency of muscle complaints in professional sports swimmers increases as training volume and intensity increases, particularly in cases with a history of such injuries. The re-searchers pay particular attention to the prevention of complaints during periods of intense training or when there is a recent injury.

Authors Olivier et al (2008) concluded that the sport of swimming at the highest level causes weakening of the shoulder joint, loosening of structures, leads to inflammation and disturbs muscle balance. Despite the fact that swimming is a symmetrical sport, prolonged and intensive swimming in crawl causes an asymmetry of strength in favour of the stronger arm.

Sport swimming places considerable stress on the shoulder joint, making it highly susceptible to instability, pain and injury (O'Donnell et al., 2005). Numerous repetitions of shoulder movements can cause asymmetry of shoulder girdle muscle strength (Bak, 1996). The force generated by the trunk muscles is transferred to the upper limb movement through the shoulder joint. Too high a load and

incorrect technique can lead to a decrease in movement efficiency, injuries, and inflammation (Smykala, 2011). Too high a variation in upper limb strength may disrupt the balance of the trunk in water, cause undesirable body rotation, and adversely affect the swimmer's technique. The consequence of this can be a decrease in the efficiency of body movement in the water (Sanders, 2013). The changes in arm muscle strength during the swimming season observed by Ramsi et al. (2004) could cause body asymmetry and lead to injury. Beach et al. (1992) and Liaghat et al. (2018) report that a reduction in endurance indices can also cause inappropriate arm function.

Numerous authors (Ramsi et al, 2004; Walker et al, 2012; Batalha et al, 2013, 2015a, 2015b; Gaudet et al, 2018) indicate that swimming techniques may be the cause of shoulder muscle strength misalignment and advocate the introduction of compensatory programmes, due to the disruption of the agonist/antagonist ratio. The literature (Richardson et al, 1980; McMaster and Troup, 1993; Weldon and Richardson, 2001; Blanch, 2004; Wolf et al, 2009; Bak, 2010; Habechian et al, 2018) cites rotator cuff strength imbalance as one of the risk factors for shoulder injury in swimmers.

However, Dischler et al (2018) did not detect an association between the number of years of training and shoulder muscle strength. Instead, they found that years of training in competitive swimming is associated with deterioration of the supraspinatus muscle and tendons and reported pain sensations and limitations in function. Manske et al (2015) showed that in adolescents, strength strengthening of the shoulder joint does not reduce the occurrence of pain. However, regardless, shoulder muscle strength symmetry should be sought to minimise the requirements of compensation programmes (Evershed et al., 2014).

Characteristic movements of the upper limbs during sports swimming

The following movements are distinguished at the shoulder joint: flexion and extension, extension and retraction, inversion and rotation (external and internal rotation). Due to the structure of the shoulder joint (multiaxial, ball and socket joint), complex movements can also occur (Marecki, 2004).

The flexion movement is performed through the activity of the following muscles: naramus (clavicular part), pectoralis major (clavicular part), and coracohumeral muscles. The straightening movement is performed by the following muscles: naramus (crest part), widest back, greater obliquus and triceps brachii (long head) (Marecki, 2004).

The following muscles are involved in the inversion movement: upper arm (shoulder), supraspinatus, biceps (long head). The following muscles are

involved in the adduction movement: epicon-dylar (clavicular and crest), pectoralis major, dor-sal widest, greater obliquus, triceps (long head), biceps (short head), and coracobrachialis (Marecki, 2004).

The inversion movement is performed by the following muscles: upper arm (crest part), sub-scapularis, obtuse minor. The turning movement is performed by the following muscles: epicondyle (clavicular part), subscapularis, dorsal widest, pectoralis major, coracoid major and coracohumeral (Marecki, 2004). When swimming the butterfly style, otherwise known as dolphin, simultaneous and symmetrical work of the upper limbs is performed. The proper phase consists in carrying out the following movements: putting the arms into the water in front with the palms turned back; adduction to the sides and down; hand bending; elbow bending; back straightening near the thighs. In the preparatory phase, the following upper limb movements are distinguished: withdrawal of the limbs from the water; abduction and forward transfer of the upper limbs over the water, together with turning the palms with the dorsal side towards the water (Butowicz, 1965; Bogajewski et al, 1969; Wróbel, 1971; Bartkowiak, 1984; Baturo et al, 1984; Kalinowski and Roszko, 1986; Bartkowiak, 1999; Troszczyński, 1999; Czabanski et al, 2003; Karpinski, 2005; Manson, 2005; Laughlin, 2007; Montgomery and Chambers, 2009; Dybinska, 2011; Newell et al, 2012; Stachura and Płatek, 2012). As the most involved muscles in the above movements are mentioned: extensors of the arm, adductors of the arm, pectoralis major, and the widest back. It is also emphasised that the muscles of the upper arm and quadriceps are also significantly involved (Czabański et al., 2003). In addition, the following muscles are also mentioned: triceps brachii, greater and lesser oblique, scapula lever, anterior cogatoid and parallelogram (Golas and Zydek, 2011).

In the backstroke, there is alternating upper limb work. In the proper phase, the following movements are performed: the straightened arm enters the water with the palm facing up; adduction downwards outwards; palm bend; elbow bend downwards; straightening and turning the forearm towards the thigh; taking the limb out of the water. The preparatory phase consists of the following movements: transfer of the straightened arm above the water surface upwards, backwards; inversion of the forearm with rotation of the trunk; insertion of the limb into the water (Butowicz, 1965; Bogajewski et al, 1969; Wróbel, 1971; Bartkowiak, 1984; Baturo et al, 1984; Kalinowski and Roszko, 1986; Bartkowiak, 1999; Troszczyński, 1999; Czabański et al, 2003; Karpiński, 2005; Man-son, 2005; Laughlin, 2007; Chollet et al, 2008; Montgomery and Chambers, 2009; Dybinska, 2011; Newell et al, 2012; Stachura and Płatek, 2012). The following muscles are mentioned as being involved in the movements of the specific phase: dorsal widest,

triceps brachii, greater obliquatus, subscapularis. The following muscles are involved in the preparatory phase movements: the shoulder, pectoralis major, biceps and coracobrachialis (Czabański et al., 2003). Golas and Zydek (2011) partially confirm the above data and list the following muscles: the upper arm, biceps, pectoralis major, broadest back, greater oblium, subscapular, quadriceps, scapula lever and anterior cogs as those most loaded during dorsal swimming.

Work of upper limbs in classical style consists in simultaneous and symmetrical work. In the proper phase, the following movements are performed: arms straightened, inverted; arm adduction to the side, down; hand bending; elbow bending; arm adduction to the trunk. In contrast, the preparatory phase consists of a single movement, which is the forward extension of the arms with conversion (Butowicz, 1965; Bogajewski et al, 1969; Wróbel, 1971; Bartkowiak, 1984; Baturó et al, 1984; Kalinowski and Roszko, 1986; Bartkowiak, 1999; Trosczyński, 1999; Czabański et al, 2003; Karpinski, 2005; Manson, 2005; Laughlin, 2007; Montgomery and Chambers, 2009; Dybinska, 2011; Newell et al, 2012; Stachura and Płatek, 2012). The work of the upper limb muscles in the proper phase is based on the following units: dorsal widest, pectoralis major, triceps brachii, obtus major, biceps brachii, coracobrachialis, subscapularis, brachiocephalic, brachialis. During the preparatory phase the following muscles work most intensively: pectoralis (clavicular and shoulder part), pectoralis major (clavicular part), triceps brachii (Czabański et al., 2003). The significance of the pectoralis major muscle in upper limb movements in classical style is particularly emphasised (Golas and Zydek, 2011).

During kayaking, alternating movements of the upper limbs are performed. The proper phase is divided into: putting the arm into the water in front of oneself; moving it down, to the side, backwards; hand bend; elbow bend with the rotation of the trunk in the long axis; straightening the arm backwards, until it is removed from the water. In the preparatory phase, the following are distinguished: inversion and transfer of the arm above the water surface in elbow flexion; bringing the arm forward (Butowicz, 1965; Bogajewski et al, 1969; Wróbel, 1971; Bartkowiak, 1984; Baturó et al, 1984; Kalinowski and Roszko, 1986; Bartkowiak, 1999; Trosczyński, 1999; Czabański et al, 2003; Karpiński, 2005; Manson, 2005; Laughlin, 2007; Montgomery and Chambers, 2009; Przybylska, 2010; Dybinska, 2011; Newell et al, 2012; Stachura and Płatek, 2012). In breaststroke kraulic movements, Czabański et al (2003) emphasise the activation of muscles such as the extensors of the arm, adductors of the arm, pectoralis major and the widest back. Golas and Zydek (2011) list in detail the following muscles: epicondyle, quadriceps, dorsal widest, triceps,

greater and lesser obecs, scapular lever, anterior cogs and parallelogram.

Strength measurement methods used in competitive swimming

For many years, the subject of interest of researchers related to sports swimming has been the strength of the athletes practicing this sport and its influence on swimming efficiency and the final sports result. Jasiakiewicz (1998a) diagnosed the triceps brachii muscle and the rectus femoris muscle in sprinters of the Ukrainian national swimming team. The biomechanical properties of the muscles, i.e. the stiffness coefficient IF and the damping coefficient IQ, were analysed during four months of the special fitness training cycle. The above parameters were qualified as objective for stage and current control. The same author, in another paper (Jasiakiewicz, 1998b) attempted to create, based on biomechanical properties (stiffness, hardness, elasticity, stickiness), a muscle model characteristic of athletes with particular sport classes in swimming.

Jasiakiewicz and Czepielew (1998a) determined the IF stiffness coefficient and IQ damping for the muscles: biceps brachii, triceps brachii, rectus femoris and gastrocnemius in swimming sprinters with different sport qualifications. It was concluded that the biomechanical properties of muscles are related to the level of sports qualification of competitive swimmers.

Currently, state-of-the-art, specialised equipment is used in this type of analysis. Roelofs et al (2017) undertook to identify changes occurring during the start period in 17 swimmers and divers. The characteristics of the head of the quadriceps femoris (lateral vastus) muscle were determined using panoramic ultrasound imaging. It was confirmed that quantifying body composition and muscle characteristics can be beneficial to improve swimming performance and prevent injuries.

Simple dynamic strength tests, conducted under land conditions, have often been used to assess the strength capabilities of swimmers. Tanaka et al (1993) questioned whether the strength gained on land could be positively transferred to the propulsive force used in water, as the specifics of training appear to differ. The authors analysed the results of two 12-person groups. The subjects in the experimental group followed a strength training programme using weightlifting machines and free weights. They reported an increase in muscle strength of between 25% and 35%, but this did not induce an improvement in swimming performance.

Garrido et al (2010a) analysed the relationship between athletic performance and the results of land-based strength and power tests. After studying 28 young athletes at national level and conducting a further study (Garrido et al., 2010b) on a group of 23

young female and male competitive swimmers, they concluded that simple land-based tests of strength and power (bench press, barbell squat, medicine ball throw, or high jump) are moderately correlated with swimming sports performance in young sprinters. In spite of a noticeable tendency to improve sprint performance due to strength training, the results so far have not allowed to conclude unequivocally that strength training significantly increases swimming performance.

Dominguez-Castells and Arellano (2011) measured power obtained in repetitions at maximum speed, during bench press. The authors studied 18 swimmers and found a moderate relationship between maximal power and swimming power. An analysis of explosive power, rather than only maximal power, was proposed. Maszczyk et al (2012) proposed the use of regression and neural models to predict outcome in sports swimming. The research project included a group of 249 young swimming athletes (age 12 ± 0.5 years) who trained and competed for four years. Their physical fitness, strength (long jump test), swimming technique, anthropometric variables, and swimming speeds were analysed. The authors proposed that such models could be used to predict future performance, as well as in the recruitment and selection of athletes for specific styles and competitions in competitive swimming.

Noriega-Sánchez et al (2015) sought to determine the extent to which anthropometric data, fitness conditions and respiratory fitness could predict the performance of a 100 m kite swimmer. Eight men and nine women, competing in swimming events at national level, were studied. Lower limb strength was measured using two tests of the squat and non-squat jump. Significant differences were detected in all tested parameters between women and men. The findings showed that forced inspiratory volume in the first second can be a good predictor of performance and should be routinely assessed in sprinters. Belfry et al (2016) investigated the effects of two different strength training programmes involving bench press and lying weight transfer behind the head on swimming performance, power, enzymatic activity and fibre type distribution in 16 male competitive swimmers. It was shown that swimmer-specific strength training (30 s, 20 repetitions), applied without concurrent swim training, improved swimming performance over both 50 m and 200 m distances.

The aim of Espada et al (2016) was to determine the relationship between swimming performance in sprint competitions and the power obtained on land and the course of movement in 22 Masters category swimmers. Again, reach jump and medicine ball throw tests were used. The results showed that swimming performance in younger Masters swimmers (30-39 years) appears to be strongly

dependent on kinematic variables. More so than on strength parameters, which were most related to swimming performance in older athletes (40-49 years). In the study by Amaro et al (2017), the aim was to determine the effect of strength and conditioning programmes conducted on land on swimming performance in 21 athletes in the age group of 13 years. Strength assessments used included medicine ball throw and high jump tests. The results showed that 6 weeks of follow-up training on land can lead to improvements in strength (also tested on land). In addition, it was noted that a 4-week adaptation period is necessary to obtain a beneficial transfer of the gained strength to the aquatic environment. Additional benefits may arise if explosive strength training is included.

In recent years, the influence of static force on athletic performance has also become a focus of research interest (Garrido et al, 2012; MacDonald et al, 2014; Bassan et al, 2016; García Ramos et al, 2016; Rebutini et al, 2016; Clemente Suárez and Arroyo-Toledo, 2017; Matthews et al, 2017; Dischler et al, 2018; Habechian et al, 2018; McLaine et al, 2018). Garrido et al (2012) attempted to determine the relationship between isometric handgrip strength (measured using a hand dynamometer) and swimming performance. The study involved 78 Portuguese swimmers, competing at national level (39 men and 39 women). Isometric handgrip strength was related to swimming performance, especially of the 100 m freestyle competition and in the female group.

The aim of the study by MacDonald et al (2014) was to determine the presence of bilateral limb strength deficits (BLD) during maximal isometric contractions of leg and hand muscles in nine female swimmers and nine non-swimmers. Deficits were detected for both groups in the measurement of lower limb muscle strength. The authors indicated that this could be due to neurological disorders, but also to other factors such as postural stability.

Bassan et al (2016) analysed the relationship between maximal isometric contraction at the elbow joint, and maximal rate of force increase (RFDmax),

and changes in biomechanical movement parameters during kayak swimming, over a distance of 400 m. Fifteen swimmers were studied. It was determined that changes in swimming technique during a gruelling test may be, at least in part, related to upper limb muscle fatigue.

García-Ramos et al (2016) investigated the correlation of different tests of lower limb strength and power on land with swimming start performance in 20 swimmers at international level. Land-based tests were conducted: "squat jump" and "countermovement jump" and jumps with additional resistance. Additionally, the strength of lower limb straightening and bending during maximal isometric

contractions was determined. No significant correlations of lower limb isometric variables with swimming start results were detected.

The aim of the study by Rebutini et al (2016) was to determine the effect of a plyometric long jump training programme in terms of torque around the lower limb joints (isometric measurement of extensors for the hip and knee joints) and the parameters obtained during the starting jump in a group of ten swimmers. The training protocol used was effective. Coaches should use distance jump training instead of vertical jump training to improve swimming start performance.

Clemente Suárez and Arroyo-Toledo (2017) analysed the psychophysiological response of the bodies of 14 swimmers during sessions of High Intensity Interval Training (HIIT). Among other things, the isometric strength of the arms was studied. The results showed a great impact of HIIT sessions on the swimmers' bodies.

Researchers Matthews et al (2017) determined the effects of training fatigue on shoulder strength, range of motion, joint position sensation and swim stride length in 17 athletes representing a high level of sport. Among other things, they performed isometric contractions of the shoulder muscles in internal and external rotation movements. A deterioration in the parameters studied was detected and a relationship between fatigue and a potential mechanism of shoulder pathology in the athletes was confirmed.

Dischler et al (2018) assessed the extent to which years of swim training influence the physical properties of the supraspinatus muscle, shoulder strength and self-reported shoulder pain and function. Isometric shoulder muscle strength was measured in 18 female student athletes of competitive swimming using a Biodex dynamometer. Although no association was detected between the number of years of training and shoulder muscle strength, it was found that many years of training in competitive swimming was associated with a deterioration of the supraspinatus muscle and its tendons and reported pain sensations and limitations in function.

In a recent study, Habechian et al (2018) reported the results of an analysis of changes in internal and external rotator strength of the shoulder in young swimmers over a 3-year cycle. The study analysed isometric shoulder strength in 31 highly skilled swimmers (14-18 years). Muscle imbalances in the shoulder girdle in young swimmers were highlighted. McLaine et al (2018) presented clinically useful measures of isometric shoulder strength for young swimmers (14-20 years). Arm flexion and extension (in 140° of visitation) and internal and external rotation (in 90° of visitation) tests were performed on 85 athletes who reported no shoulder pain. Normative values and proportions of shoulder muscle strength were determined. A significant difference in

relative strength was found between males and females and no differences in strength ratios were record-ed. The relative strength of the dominant and non-dominant arm for swimmers with and without shoulder pain was not significantly different.

A frequently used tool to measure the force produced directly in the aquatic environment is the tethered swimming test. As early as the 1950s, Absaliamov (1955) conducted research on kraulists of various sporting levels. He analysed the amount of propulsive force generated using the tethered swimming test.

Jasiakiewicz and Czepielew (1998b) studied the special physical fitness of swimming sprinters. A tethered swimming test was used to assess maximal strength - measuring 5 s, for strength endurance - measuring 30 s. A DPU-0.1-2 dynamometer was used. Crowe et al (1999) also investigated the relationship between strength tests and swimming performance. Among 65 university level swimmers, strength was tested by bench press lying down, bar pull to chest sitting down and el-bow straightening behind the head. Power was determined by a medicine ball throw test from behind the head. Swimming power was tested with a 30 s maximum tethered kayak swim test. In contrast to other results, the authors presented the conclusion that muscle strength was not related to swimming performance in sprinting competitions.

Aspenes et al (2009) studied 26 swimmers, over 14 years of age, reporting no complaints, training regularly. The researchers wanted to test the effectiveness of combined strength and endurance training. Strength and power parameters were obtained using a tethered swimming test (Digital Force Indicator, AEP, Modena, Italy) and strength tests performed on land (Crossover Cables, Technogym, Gambettola, Italy). The shore-based strength training programme improved middle distance swimming performance.

Morouço et al (2011a, 2011c) attempted to determine the relationship between swimming performance in 32 competitive swimmers and the strength developed during tethered swimming (30 s test), in four swimming styles. Additionally, they analysed whether relative strength values were better determinants of swimming performance than absolute values. The data showed that absolute strength values were more related to swimming performance than relative values (normalised to body weight). The tethered swim test appeared to be a suitable tool for assessing swimmer strength and a helpful predictor of performance in sprint competitions.

In subsequent publications, Morouço et al (2011b) analysed the relationships between strength and power obtained on land and swimming performance in ten national level athletes. Power was assessed by the tests of the barbell squat, bench press and pulling

the bar behind the head. Strength was assessed with a 30 s maximum effort test of tethered kelp swimming using the entire style, upper limbs only and lower limbs only. The usefulness of these tests for studying strength levels and predicting athletic performance was assessed.

A study by Neiva et al (2011) was conducted to determine the effect of a warm-up on the performance of tethered, high-intensity, kayak swimming (30 s test). The results obtained from measurements of ten swimmers competing at national level confirmed an improvement in the swimmer's maximum and average strength that was due to the prior warm-up.

Dos Santos et al (2012) attempted to assess the relationship between propulsive force during tethered swimming and shoulder muscle area (estimated by anthropometric and skinfold measurements). Twenty-eight athletes participated in the study. The results of this study showed the existence of a relationship between thrust force and muscle mass.

The aim of the study conducted by the team of Sadowski et al (2012) was to evaluate the effect of strength training conducted on land on strength obtained in land tests, strength during swimming and swimming performance in 26 young swimmers. It was not conclusively found that strength training enabled improved swimming performance, although a trend towards improved tethered swimming performance was noted.

The study by Kalva Filho et al (2015) examined the relationship between the variables of a 3-min aerobic exercise test, the intensity corresponding to the minimum lactate content, and the parameters obtained during anaerobic work (400 m), under tethered swimming conditions. Thirty swimmers took part in the measurements. Maximum force determined during the tethered swimming test was related to oxidative metabolism. It was suggested that this measurement could be used to assess the aerobic capacity of the athletes. However, work performed during this test was not correlated with aerobic capacity.

The objectives of the study by Morouço et al (2014) were to compare biomechanical and physiological performance between tethered swimming (30 s) and free swimming (50 m kite) tests. Additionally, the effect of strength on short-distance swimming performance was assessed.

A total of 34 athletes, representing different sport levels took part in the measurements. A non-linear relationship between swimming speed and maximal force was detected, while linear relationships existed with maximal impulse values. It was confirmed that tethered swimming does not significantly affect biomechanical and physiological responses compared

to free swimming, and that maximum impulse during the stroke should be used to assess the balance between force and the ability to apply force effectively during sprint swimming.

In the following years, Morouço et al (2015) investigated the relative contribution of upper limb and lower limb work to kite swimming performance in 23 young swimmers at national level. Eleven females and 12 males were studied. They each performed three trials of 30 s of tethered swimming (swimming full style, using only the upper limbs and using only the lower limbs). The results showed that the work of the lower limbs alone played an important role in short-term high-intensity efforts and that the methodology used could be useful for identifying strength and coordination deficits.

Barbosa et al (2016) investigated the effect of conditioning training using swimmer's feet and a parachute on propulsive power in eight competitive swimmers. A 10-second tethered swimming test was conducted. Although conditioning training had a negative effect on propulsive force values, among weaker swimmers the performance deterioration was greater than in stronger swimmers. The proposed conditioning training was not recommended for swimmers during the competitive period.

Loturco et al (2016) also tested the relationships between measures of strength on land, tethered swimming parameters and swimming performance. Ten high-level young male swimmers were assessed using tests of maximum isometric strength in bench press and half squat, average power in reach jumps, peak strength, average strength, rate of force development (RFD), impulse (tethered swimming) and swimming time. Significant correlations were confirmed between land-based strength assessments and tethered swimming and swimming performance. Additionally, the authors encouraged coaches to implement strategies to increase leg strength in swimming sprinters.

The study by Santos et al (2016) aimed to determine whether propulsive force (peak force, average force, impulse and rate of force development) and upper limb duty cycle parameters changed during 2 minutes of tethered kayak swimming and whether they correlated with turnout and swimming speed over a 200 m kayak distance. The study was conducted on a group of 21 swimmers. Propulsive force and movement frequency changed during 2 minutes of tethered swimming, while peak force was the highest correlating variable.

Łubkowska et al (2017) attempted to determine the correlation between the athletic performance of 14 competitive swimmers and general and special strength. The following tests were performed: bench press, pull-up and pull-down of the overhead lift bar to the chest, test on the "swim bench" apparatus, as well as the tethered swimming test. High levels of

general and special strength were detected in the swimmers tested. Those subjects who showed the greatest progress in the general and special strength tests showed the greatest improvement in swimming performance over the competition season. It was suggested that those whose progress in general and special strength tests was least significant should attempt to make progress by developing other technical and coordination skills.

The aim of the study by Santos et al (2017) was to determine whether land and tethered swimming strength tests could correlate with 200 m kite swimming performance, and whether the aforementioned tests were able to identify bilateral symmetry in strength production. The subjects of the study were 18 swimmers. They performed a 15 s tethered swimming test and an isometric strength test. It was concluded that both isometric force and tethered swimming tests could be used to identify force asymmetry in swimming.

Strzała et al (2017) analysed the influence of body characteristics, force generated in land tests (reach jump, isometric force of the elbow and knee joints) and force obtained during tethered swimming, on the speed of 50 m kayak swimming in athletes in youth and junior groups. The authors suggested supplementing the evaluation of swimming sprint (in addition to the above-mentioned elements) with measurements of actual swimming technique parameters.

In a recent study, Nagle Zera et al (2018) assessed the reliability and accuracy of a 30 s tethered swimming test. Twenty-nine male and female athletes participated in the measurements. This study showed that the tethered swimming test is a reliable tool, moderately related to swimming performance, producing similar physiological responses to free swimming. It was reported that this test should be used during regular monitoring as part of a swim training programme.

Continuous technological development allows the creation of newer and more accurate apparatuses, which analyse and describe in detail the work of human muscles. For the purposes of diagnosing the strength capabilities of swimmers, measurement under static conditions (isometric contraction) and dynamic measurement, which consists in lifting a standard weight, are considered insufficient. The method of assessing thrust during tethered swimming does not provide the possibility to analyse changes in force during a single stroke. Measurement under isokinetic conditions is considered more accurate and correlates much higher with athletic performance, speed of movement, or thrust (Platonov, 1997). Shoulder muscle strength determined in an isokinetic stance has been found to be highly correlated with swimming speed over

various distances: $r = 0.90$ (Sharp et al., 1982), $r = 0.82$; $r = 0.83$ (Hawley and Williams, 1991).

The repeatability of isokinetic assessment of arm strength is satisfactory provided that the recommendations of the test method are followed. Isokinetic measurement is a valid, reliable and objective method of assessing arm muscle strength and detecting deficits in specific muscle groups. Such measurement is a valuable tool for orienting the direction of rehabilitation and an accurate means of tracking progress (Shirakura et al, 1992; Rokito et al, 1996; Codine et al, 2005; Bryant et al, 2009, 2011; Eitzen et al, 2010). Strength refers to the ability to actively develop muscle tension regardless of the testing mode (isometric, isotonic, isokinetic), the angular velocity used, or the type of muscle contraction (isometric, concentric, eccentric). The choice of the correct test depends on the task to be performed, but almost all ways of expressing the quantitative values of muscular strength have reciprocal relationships. Strength testing assesses the patient's ability to voluntarily apply maximum tension to skeletal muscles through a lever arm. Because of this, all clinical force measurements, regardless of test mode, should be expressed in units of torque (Sapega and Kelley, 1994).

During the analysis of the available national and international literature, numerous materials were found concerning isokinetic studies of the shoulder joint of competitive swimmers, in internal and external rotation movements only (Rupp et al, 1995; Bak and Magnusson, 1997; Swanik et al, 2002a; Ramsi et al, 2004; West et al, 2005; Gozlan et al, 2006; Olivier et al, 2008; Batalha et al, 2012, 2013, 2014, 2015a, 2015b; Wiażewicz, 2015; Wiażewicz and Kolbowicz, 2015; Dekerle and Peterson, 2016; Wiażewicz and Czekala, 2017; Gaudet et al, 2018; Liaghat et al, 2018). Significantly fewer literature items were related to comprehensive studies, i.e. isokinetic analysis of arm movements in several planes (Beach et al, 1992; McMaster et al, 1992; Magnusson et al, 1995; Alonso-Cortés Fradejas et al, 2006; Van De Velde et al, 2011; Nakashima et al, 2012; Manske et al, 2015;). On the other hand, a significant gap in strength studies concerning the flexion and extension movements of the arm has been noted (Moffroid et al, 1969; Wattanaprakornkul et al, 2011; Girold et al, 2012), so a study of our own was initiated (Wiażewicz, 2016; Wiażewicz and Eider, 2016).

Research in internal and external rotation of the arm

Rupp et al (1995) investigated the incidence and basis of shoulder complaints in 22 athletes from the national elite swimmers. They used a questionnaire, clinical examination and isokinetic measurement of internal and external rotation of the shoulder. Rotator cuff muscle strength imbalance was cited as one of the causes of shoulder injuries.

Bak and Magnusson (1997) compared 15 swimming athletes: seven with shoulder pain and eight without pain. Torques in internal and external rotation movements were analysed.

According to the authors, rehabilitation or earlier injury prevention should be based on strengthening the external rotators and correcting deficits in inward movement. Swanik et al (2002) determined the effect of plyometric training on muscle strength among 24 female swimmers. Arm internal and external rotation tests, on a Biodex II dynamometer, were performed before and after a 6-week plyometric training programme. The above measures increased proprioception properties and muscle performance, resulting in significant neuromuscular benefits, also for shoulder rehabilitation.

Ramsi et al (2004) investigated the strength of internal and external rotation in 27 high school students, competitive swimmers, during a 12-week competitive season. They detected a significant increase in strength in the internal rotation movement, with no equally high improvement in external rotation. It was pointed out that this could result in pathological conditions of the shoulder in the future.

West et al (2005) tested a group of 13 athletes (seven females and six males) from the Masters swimming section and a matched control group on a Kin-Com dynamometer. Peak torque and eccentric and concentric work rates for inward and outward rotation movements were analysed. Strength profiles were determined for each subject and individual cues were suggested and implemented in training.

Gozlan et al (2006) compared the results of peak torque and reciprocal internal and external rotator ratios among 42 competitive swimmers, volleyball players and tennis players. Measurements at 60°/s and 180°/s were made on a Cybex Norm apparatus. An asymmetry related to the dominance of the fitter arm was detected in the swimmers.

Olivier et al (2008) studied 20 swimming athletes at the highest national level who specialised in crawl swimming. An isokinetic test of internal and external rotation, at 60°/s revealed a lack of symmetry of force, in terms of one limb and in the comparison of dissimilar limbs.

Batalha et al (2012) in their study described the balance, fatigability and isokinetic rotator cuff force profile in internal and external rotation movements in 60 swimming athletes. They used a Biodex S3 dynamometer and 60°/s and 180°/s protocols. The athletes showed significantly higher internal rotator force values and greater muscle strength imbalances than the control group.

In a subsequent study, Batalha et al (2013) observed changes in rotator cuff strength and endurance in 20

young athletes during the competitive swimming season and among 16 control subjects. They studied peak torque and reciprocal internal and external rotation ratios at 60°/s and 180°/s. Significant intergroup differences were observed especially in strength and endurance values in internal rotation, which favoured the building of muscle imbalances.

Batalha et al (2014) then conducted an experiment on 40 young athletes. In the experimental group, land-based strength training was discontinued after 16 weeks of swim training. This break lasted another 16 weeks. The strength and balance of the internal and external rotator muscles of the shoulder were observed.

Not performing strength exercises on land resulted in a decrease in the ratio of agonists to antagonists.

Batalha et al (2015a) studied 27 young athletes before and after 16 weeks of a swimming macro-cycle. The maximum torque of the internal and external rotators of the shoulder were compared. Three repetitions at 60°/s and 20 repetitions at 180°/s were measured on a Biodex S3 dynamometer. Significant training changes in inward movement and agonist to antagonist ratios were detected, affecting the muscle imbalance of the athletes.

In a subsequent study, Batalha et al (2015b) analysed the effects of a compensatory training programme using "Thera-Band" tapes on the strength and balance of the shoulder internal and external rotator muscles in a group of 40 young swimmers. The results indicated that the recommended exercises could result in increased absolute strength values and greater muscle balance in shoulder rotational movements.

Wiażewicz (2015) analysed strength parameters in a group of five athletes of the City Swimming Club in Szczecin who were under the care of the Swimming Training Centre. The shoulder joint was assessed in external rotation and internal rotation movements. The created documentation, characteristic for a given period in the athlete's career and for a moment in the training cycle, can be used for control in the process of preparation for the Olympic Games or to recreate the state from before a possible injury. It was postulated that coaches should introduce compensatory changes for deficiencies in strength parameters, especially in movements not typical for swimming.

The aim of the study by authors Wiażewicz and Kolbowicz (2015) was to analyse the changes in torque values at the shoulder joint, depending on the position of the limb for the tested athletes, in the movement of internal and external rotation. Five athletes representing a very high level in sports swimming (international and masters sport class) were studied. Abnormalities were detected during

torque changes in the internal and external rotation movement, and the coaches were in-formed about this. Through this, the implementation of the training programme of sports swimming athletes preparing to perform in the Games of the XXXI Olympiad in Rio de Janeiro in 2016 was supported. The authors recommended the use of available testing equipment and the cyclic repetition of measurements.

Dekerle and Paterson (2016) attempted to determine shoulder internal rotator muscle fatigue during prolonged submaximal swimming efforts performed in two different speed areas. The study was conducted on a group of eight athletes. The recovery interval (lasting 2.5 min) used during submaximal speed swimming probably had a positive effect on muscle fatigue, but the relationship between reduced swimming stride length and reduced muscle strength should be considered in more detail.

The aim of the study by Wiażewicz and Czekala (2017) was to analyse strength parameters in the rotation movement of the shoulder joint in one high-level (international champion) athlete preparing to perform at the 2016 Olympic Games in Rio de Janeiro. It was requested that a programme of compensatory land exercises in the rotation movement of the shoulder joint be introduced as soon as possible. Additionally, it was recognised that peak torque may not be an entirely appropriate determinant of shoulder muscle strength symmetry.

Gaudet et al (2018) attempted to assess the effect of repeated maximal internal and external arm rotations, on muscle strength and activity. The rotations were performed in an isokinetic mode. The measurement was performed on a group of 24 swimmers. Significant fatigue of the rotator muscles was observed during repeated arm movements. The authors concluded that this could impair shoulder stability and consequently cause injury.

Liaghat et al (2018) studied 38 competitive swimmers to determine the relationship between hypermobility in the shoulder joints and shoulder strength, fatigue development and muscle activity during shoulder rotations. A concentric protocol was used to measure isokinetic strength in internal and external rotations at 60°/s (5 repetitions) and 180°/s (10 repetitions). Strength and fatigue factor deficits were detected, which could increase the risk of shoulder injury in young athletes.

Beach et al (1992) compared the relationship between shoulder muscle flexibility, strength and endurance with the occurrence of soreness in a group of 32 swimming athletes from the United States. A Cybex II dynamometer was used to measure strength and endurance in the movements of internal and external rotation and adduction and abduction. The authors concluded that clinical assessment should pay special attention to the strength indices of the adductors and external rotators.

McMaster et al (1992) evaluated torque production in inversion and adduction movements as well as internal and external rotation in competitive swimmers. The study was performed on a Cybex II dynamometer. An increase in torque was found in most of the movements studied. Specific changes were observed, which could be caused by long-term repetition of the above-mentioned movements associated with sports training.

Magnusson et al (1995) created muscle strength profiles of 24 American Masters athletes. Isokinetic testing was performed in the movements of trunk flexion and extension, knee flexion and extension, and shoulder internal, external rotation and inversion. Strength in relation to body weight, range of motion and swimming time for 50 yards were studied. Flexion, trunk straightening and internal rotation of the arm correlated with a decrease in swimming time over the above distance.

Alonso-Cortés Fradejas et al (2006) studied the concentric work of the arm in a group of 18 young sports swimmers in three movements: flexion and extension, abduction and adduction, and internal and external rotation. A Biodex S3 dynamometer was used for the study. Velocities of 60°/s and 180°/s were chosen for the study. The authors reported that analysis of the above movements provided the most functional approach to isokinetic assessment of the shoulder.

Van De Velde et al (2011) investigated the effects of 12 weeks of training on muscle strength and endurance in the scapular inversion and adduction movements in 18 adult competitive swimmers. Maximum torque, fatigue index and strength were measured on a dynamometer before and after the training programme. Both strength and endurance improvement programmes had a positive effect on absolute scapular muscle strength. Neither programme had any effect on scapular muscle strength. It was suggested that the results may be valuable for trainers and physiotherapists.

Nakashima et al (2012) searched for a way to improve swimming speed and propulsion production by optimising the stroke in the crawl. Five college-level athletes in training were studied. Among others, the isokinetic arm was measured in flexion/extension, inversion/adversion and internal/external rotation movements. The velocity and stroke results obtained were similar to those occurring during sports competition.

Manske et al (2015) used isokinetic measurements of shoulder flexion, extension, inversion, internal rotation and external rotation to investigate the relationship between strength at the shoulder joint and pain in adolescent swimming athletes. The 11 subjects in the experimental group performing a strengthening shoulder training programme showed a significant increase in strength in the external

rotation movement, compared to 10 subjects in the control group. Shoulder pain was not significantly different between the groups.

Apart from the previously mentioned planes of motion, attention was also paid to the analysis of bending and straightening of the arm in swimmers. Golas and Zydek (2011) emphasise that the basis of rowing movements in the swimming stroke, butterfly and classic style is the straightening of the arm, whereas in the diving stroke - bending. The arm straightening movement is comparable to the course of the specific phase of the rowing movement in the swimming stroke, butterfly and classic style. It was also noted that the musculature was similarly engaged between a given movement and the actual phase of the arm movement in all four swimming styles. In addition, Beach et al (1992) report that athletes spend 80% of their training time performing crawl exercises, regardless of swimming specialisation.

Moffroid et al (1969) report that isokinetic testing in flexion and extension movements of the arm shows a correlation coefficient of up to 0.75 to 0.91 in a "test-retest" study. Flexion and straightening movements are considered to be additional patterns of isokinetic measurement, providing the possibility of obtaining more detailed information on arm function.

Wattanaprakornkul et al (2011) showed that the anterior or posterior parts of the rotator ring were activated during the flexion and extension movements of the arm, similar to the external and internal rotation movements. The muscles were activated in a characteristic way that prevents the head of the humerus from moving in an antero-posterior direction. The presented method of activating the rotator ring muscles, during flexion and extension movements had a stabilising formula, and thus may be a much more functional method of training the shoulder muscles than rotation exercises, which activate the rotator ring in an isolated manner to produce torque.

A study by Girolid et al (2012) was conducted to compare the effects of land-based strength training with a muscle electrical stimulation programme in swimmers. A group of 24 swimmers at national level were subjected to a four-week training intervention. Maximum torque in the arm straightening movement at different speeds (from 60°/s to 180°/s) was tested using an isokinetic dynamometer. No significant differences in swimming speed were observed between groups, and there were no significant changes in the control group. Programmes combining swim training with strength improvement "on land" or electrical stimulation were more effective than swimming training alone, as they resulted in an increase in swimming performance in sprint competitions.

Wiażewicz (2016) attempted to detect abnormalities and deficits among shoulder joint strength parameters in five young swimmers from Szczecin. Isokinetic measurements were made in shoulder flexion and extension movements. The individual athletes were at risk of shoulder injury. It became necessary to start a compensatory exercise programme.

The aim of the study by Wiażewicz and Eider (2016) was to investigate whether Masters swimming affects strength disparity? Additionally, the correlation between the number of years of sports swimming training in a swimmer's past and the deficit in strength parameters was analysed. A group of 18 competitive swimmers competing in the Masters category was studied. Strength parameters were assessed using a Biodex S4 dynamometer, in shoulder extension and flexion movements. No significant differences were detected between the body sides. It was concluded that swimming in the Masters category had no effect on bilateral strength disparities or agonist-antagonist differences.

Kegerreis and Malone (1982) described different torque curve patterns, but for the quadriceps, which were associated with different knee injuries. In contrast, Stratford et al (1987) reported that the shape of the curves did not correlate significantly with the diagnosis of knee injury and recommended caution in isokinetic diagnosis. However, Shirakura et al (1992) and Ikeda et al (2002) propose an in-depth analysis of knee joint torque curves plotted against time to detect bilateral differences and abnormal values. Tsepis et al (2004) mention significant asymmetry and a reduction in the smoothness of the torque curve over time as elements characteristic of limbs with trauma.

Qualitative assessment of isokinetic test results can be used to detect deviations, but the use of subjective analysis should not be the basis for clinical decisions (Ayalon et al, 2001, 2002). Many authors (Kegerreis and Malone, 1982; Shirakura et al, 1992; Ikeda et al, 2002; Tsepis et al, 2004; Eitzen et al, 2010; Bryant et al, 2011; Almosnino et al, 2014) during isokinetic testing of the knee joint have more accurately examined lower limb muscle strength by analysing torque curve plots. It is highlighted that the above measures can provide interesting functional information, in addition to the standard values (peak torque, average torque, work or power) presented by the post-test protocol.

Similar conclusions were presented by Platonov (1997), Wiażewicz and Kolbowicz (2015) and Wiażewicz (2016), regarding the upper limb. Detection of abnormalities in the course of arm movement on the graph allowed to support the training programme of sports swimming athletes. The necessity of continuing the research, also in a cyclic formula, was also stressed (Wiażewicz,

Kolbowicz, 2015; Wiażewicz, 2016; Wiażewicz, Czekala, 2017).

The final sports result in swimming is influenced by many elements connected with the individual preparation of the athlete: general fitness, speed, endurance and muscle strength, technique, coordination, flexibility, energy security of the body (Pansold et al, 1982; Baturo et al, 1984; Bartkowiak, 1999; Woźny, 2012). Additionally, the following components are mentioned: implementation of tactical assumptions, competitive experience, characteristics of the athlete's psyche, training characteristics, activities of the coaching staff, daytime disposition, health, activities of the jury, luck and diet (Woźny, 2012). It may be that in athletes representing a high level of sport, strength ability was a barrier to achieving higher swimming performance. If this is the case, it is suggested to develop other individual abilities of the swimmer's body, related, for example, to technique, coordination, aerobic or anaerobic endurance (Lach, Rolski, 1996; Łubkowska et al., 2017).

Conclusion

Sport swimming is one of the most demanding sports. The subject of interest of the scientists connected of sports swimming was the level of strength ability of the competitors practising this sport and the influence of this ability on the final sports result. The most important factors determining success in sports swimming: proper somatic constitution, correct morphological and physiological development, environmental and living conditions, level of motor abilities, personality traits, age of starting training. Developing all the parameters of a

swimmer: optimal levels of strength, power endurance, aerobic and anaerobic energy delivery mechanisms, cycle length, swimming speed, technique and coordination can ensure the achievement of a high level of athleticism. Ultimately, however, authors involved in the analysis of swimming performance classify sport swimming as a discipline in which strength level is largely responsible for the final result. A thorough review of scientific publications indicates that strength parameters of the shoulder girdle muscles played a very important role on the sports performance of swimmers. Proper strength preparation is therefore a very important component of the final result in sports swimming. The changes of some strength parameters of shoulder muscles positively affected sports achievements. The level of strength capabilities of shoulder muscles of female and male high-level competitive swimmers influences their final athlete performance, so these strength parameters should be developed. It is worth using the method of isokinetic shoulder measurement to regularly and periodically monitor female and male high-level competitive swimmers and lead the long-term personalized programmes to improve particular parameters of shoulder muscle strength, thus their sports achievements. Masters swimming has no effect on bilateral strength disparities, the programmes combining swim training with 'on land' strength improvement or electrical stimulation are more effective than swim training alone. Significant fatigue of the rotator muscles can impair shoulder stability and result in injury. Increased strength in the internal rotation movement may result in future pathological conditions of the shoulder. The results of the analysis of the presented literature can be valuable for trainers and physiotherapists.

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