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Strength and Power Training For Front Crawl Swimmers

Rinnulikrooli ujujate jõu ning võimsuse treening

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CONTENTS

ABBREVIATIONS

SR – stroke rate

SL – stroke length

OSt – overstrength

OSp – overspeed

RAS – resisted- and assisted-sprint

INTRODUCTION

Competitive swimming has a long history and is currently one of the largest Olympic sports, with 17 pool events. Different aspects separate swimming from most other sports like prone position, propulsion, which is created by simultaneous use of arms and legs, water immersion (i.e. hydrostatic pressure on thorax and controlled breathing), propulsive forces that are applied against a fluctuant element. After the swim-suit restrictions (implemented 01.01.2010) the equipment has minimal influence on swimmer's performance.

Front crawl is the most used swimming stroke in freestyle events and is the fastest swimming technique used by swimmers in freestyle events. Specific resistance training programs are necessary to develop muscular functions such as strength and power, which are needed for front crawl events. Modern swimming training regimes emphasize performance level through both – training in water and muscle strength training.

The purpose of this thesis was to give a brief overview about different resistance programs in water and dry-land. This thesis contains the chapters of front crawl biomechanical factors and performance enhancement for swimmers, also the use of strength and power training programs for front crawl swimmers.

This thesis is created for persons, who would like to know more about strength and power training programs for front crawl swimming. It can also be used as teaching material for beginning swimming coaches because it includes the basics of front crawl swimming technique. There is also explained why it is important to combine resistance training in water and dry-land in swimming.

The following databases were used for this thesis: PubMed, ScienceDirect and SPORTDiscus. These databases were searched with key words: strength training, power training, front crawl, swimming, stroke characteristics.

1. FRONT CRAWL BIOMECHANICAL FACTORS

1.1. Stroke length and stroke rate

In freestyle races elite swimmers compete front crawl with optimal stroke length and six beat kick in competition (Persyn et al., 1983). In short distance events, elite swimmers show high stroke length and use six beat kick throughout entire race (Persyn et al., 1983; Seifert et al., 2005). The front crawl stroke is swam at an exact swim velocity which requires application of an effective swimming technique. Swimming velocity is determined by stroke rate (SR), stroke length (SL), to a small degree kicking and significant physiological elements (Sortwell, 2012).

A swimmer's ability to reach maximum speed is determined by the ability to cover a long distance per stroke while stroking at maximum frequency. Stroke length has been the best discriminative factor of swim velocity (Seifert et al., 2007) and is heavily linked with better swimming economy (Costill et al., 1985a). Ability to cover a long distance per stroke shows a greater propulsive efficiency and reduction of drag (Toussaint & Beek, 1992). Professional swimmers have long stroke lengths which feature their level of skill and superior expertise (Chollet et al., 1997; Wakayoshi et al., 1993). They also tend to modify the stroke parameters (SR and SL) when they get tired (Dekerle et al., 2005). The coach has to determine the best combination between swimmer's stroke length and stroke rate to swim at the highest velocity (Dekerle et al., 2005), they must increase stroke length to reach such a level to begin with (Chollet et al., 1997). For example, growth of triceps brachii strength and power allows full completion of pull from midpoint to start of recovery, and also enhances optimal force development and increases of stroke rate with greater force and length (Sortwell, 2012).

1.2. Leg kick quantity

Maximal leg strength is associated with reaction time in the start, diving distance, entry velocity from the dive, may also influence turn time or kick-off velocity after the turns. Relevant parameters might be maximal strength and the rate of force development in quadriceps and hamstrings from a starting position and in water when kicking away from the wall (Aspenes & Karlsen, 2012).

In competitive sprint front crawl distance events in swimming the most common kicking pattern used throughout the race is the six beat kick (Toussaint & Beek, 1992). The kick plays an important role assisting both balance, stabilisation to the trunk and propulsion to the front crawl stroke. The kick improves the efficacy of the upper body and overall efficiency in the front crawl stroke by keeping the body stable, elevating the lower limbs, improved buoyancy and roll motion fluctuation (Toussaint et al., 2002). A swimmer with good body control and balance in the water is characterised with a 6 beat kick (Costill et al., 1992; Toussaint et al., 1988). The 6 beat kick allows the swimmer to maintain balance, stability and rhythm and it also contributes to propulsion in water (Sortwell, 2012).

1.3. Stability control and body roll

In front crawl, good body control allows the swimmer to pull further and correctly, enabling longer stroke length. Poor control of body and balance in the water will lead to the swimmer moving arms less efficiently in an attempt to gain stability (Toussaint et al., 2002).

Good body control assists with best stroke length, which is more efficient and hence allows to swim a greater distance with each pull. Characteristics which allow to swim greater distance with each pull is the six beat kick and body roll. In stroke length leaded front crawl the swimmer tends to have greater amount of body roll. This larger amount of body roll allows the swimmer to reach in further in front for the entry phase of the stroke (Sanders & Psycharakis, 2009) (Figure 1). The longer reach in the entry phase increases the distance per stroke or stroke length.

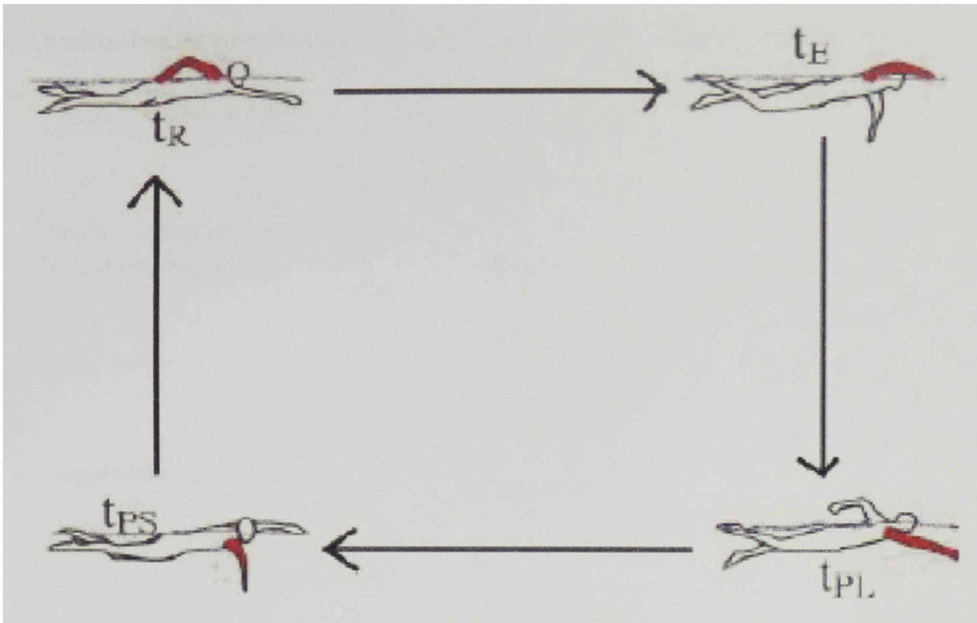

Figure 1. Front crawl intracyclic phases; tE= commencement of the entry phase (non propulsive); tPL= commencement of the first propulsion phase; tPS= commencement of the second propulsive phase; tR= commencement of the recovery phase (non propulsive) (Sortwell, 2011).

1.4. Qualitative biomechanical analysis of front crawl

It is important to know which muscle groups and joint actions are used in the front crawl. Table 1 and appendixes 1, 2 show the muscle groups and their function at specific front crawl phases of the arm stroke and leg kick. This information helps swimming coaches to choose the best exercises which mirror the joints and muscles used in front crawl and will benefit the swimmer (Sortwell, 2012).

Table 1. Qualitative biomechanical analysis main phases of the front crawl (Pink et al., 1991).

Phase of arm stroke	Muscle groups	Function
Catch – when the hand enters the water	Upper trapezius, rhomboids	Upper trapezius elevates the scapula and the rhomboids retract the scapula
	Rhomboids	Retract the scapula
	Serratus anterior	Protracts and rotates the scapula up
Just after the catch	Pectoralis major	Adducts and extends humerus
	Teres minor	Balances internal rotation
	Coracobrachialis	Flexion of the arm
	Biceps brachii	Flexion of the arm
Midpoint – pull through	Latissimus dorsi	Pull through
	Subscapularis	Pull through
	Coracobrachialis	Flexion of the arm
	Biceps brachii	Flexion of the arm
Pull through	Triceps brachii	Extension of the elbow
Through recovery	Deltoid	Arm recovery
	Supraspinatus	Arm recovery

Phase of the kick	Muscle groups	Function
Upward beat of kick	Gluteal muscles, biceps femoris, semitendinous, semimembranous, and gracilis	Hip extension
Downward beat of kick	Iliopsoas, rectus femoris	Flexion of the hip
	Quadriceps	Extension of the knee

2. PERFORMANCE ENHANCEMENT FOR FRONT CRAWL SWIMMERS

The muscular functions such as endurance, power, and strength are important components in shaping the swimmer's performance, especially when power is highly related to short event records such as 50m front crawl (Hawely et al., 1992). In front crawl swimming, explosive strength and power are considered an important component of performance (Costill et al., 1985b).

Strength and power development is an important component for success in swimming events (Costill et al., 1986). Elite swimmers swim 40 - 80 km each week to maintain stroke efficiency and develop the aerobic capacity and speed endurance which are important to complete front crawl events with little deceleration towards the finish. A training program for strength power resistance results in increased or maintained of type II fibers cross-sectional area, increased peak force, type I faster fibers contraction, improved swim bench power and swim performance (Trappe et al., 2000). Therefore a strength and power resistance program is needed for a front crawl swimmer to maintain and improve the maximal speed of skeletal muscle fibers and fiber size. In regards to the practical implications for the swimmer, increasing arm strength is beneficial so swimmer can apply more force in the stroke over a longer period of time, creating a good impulse rather than needing to have rely on a high stroke rate (Sortwell, 2012).

2.1. Strength training

Improved strength enhances power production through adaptations of the fibers and power training leads to adaptations in the fiber subtypes and neuromuscular system. In a study by Cronin et al. (2000), it was found that larger maximal strength was followed by a greater instantaneous power. The same authors highlighted that the neuromuscular ability to generate the largest amount of power per time unit is of greater importance than maximal strength in concentric actions. In a study by Stone et al. (2003), it was concluded that enhanced maximal strength was the main element in improving power; whereas power-type strength training with higher shortening velocities and lighter loads has shown to increase the force production at greater velocities, as well as development of power which seems to facilitate the neuromuscular system (Sleivert et al., 1995).

Power depends on strength and speed. An improvement of maximal strength influences power production. The improvement in the athletes power relies on a development of the neuromuscular system. Maximal strength is transferred to power, muscles of fast response and explosive adaptation for performance are needed. In particular, the use of medicine ball for elastic exercise plays a role for positive improvement of power. Girold et al. (2007) study demonstrated that combining swimming with dynamic strength training was more efficient than the swimming program alone in increasing sprint performance. The added benefits of dynamic strength training to front crawl is an increased stroke depth and rate whereas the added benefit of dry maximal strength training is the strength gain in concentric contraction of the elbow extensors which is a good predictor of sprint performance (Girold et al., 2007).

2.2. Power training

Power has been shown to correlate with swimming performance in 100m freestyle (Toussaint & Vervoorn, 1990). Top level swimmers who participate in dry-land training focusing on strength development only, do not increase 100m swimming performance (Tanaka et al., 1993). However high-resistance strength training combined with a high velocity dynamic training enhances peak power and stroke rate. Adaptation of faster stroke rate without decrease in stroke length is caused by adaptational changes in the nervous system (Delecluse et al., 1995).

Power training leads to increased muscle fiber pennation angle (Aagaard et al., 2002). This is important because it allows for greater increase type II muscle fibers cross-sectional area and composition (Andersen & Aagaard, 2000). Power training also induces a slow (type I) to fast (type II) shift in myosin heavy chain (MHC) isoforms. The benefit of the increase in number of type II MHC isoforms is faster contraction due to; large motor neurons, faster rate of release of calcium by the sarcoplasmic reticulum and the activity of myosin ATPase (Fitts & Widrick, 1996). The combined effect of these three specific changes is increased; contractile force, rate of force production and power.

Power training also leads to specific neural adaptations, such as the increased activation of motor units and rate of activation of the motor units (Häkkinen, 1994). The benefit of the increased rate of activation or motor unit recruitment frequency is greater rate of force development (Behm, 1995), and consequently mechanical power is maximised (Harris et al., 2000). A combination of power and strength training has a greatest impact on improvement of the velocity and force time curve in swimming (Sortwell, 2012).

2.3. Biokinetic swim bench training

The most prevalent dry-land training device for swimming is the biokinetic swim bench (Figure 2). Although the swim bench is suggested to reproduce some elements of regular swimming, it cannot adopt the biomechanical aspects related to the athletes feel for the water (i.e. the dragpropulsion relationship) or circumstances related to water immersion (controlled breathing, hydrostatic pressure and the antigravity effect) (Aspenes & Karlsen, 2012).

Costill et al. (1980) reported that following resistance training on the biokinetic swim bench, swimmers increased their power output by 28% with concomitant improvement in sprinting performance of 3.6%. In their study, however, a small number of subjects were used, and swim training was discontinued during the resistance training period. In addition the specificity of the swim bench has been controversial. On the swim bench, the legs and trunk are inactive, and shoulder does not roll as it does in the front crawl swimming. Electromyographic evidence suggests that the time course, amplitude, and frequencies of muscles employed on the bench may be different from that in swimming. On the bench, the pulling path traveled by the hand is longer. The distribution of pulling forces at various joint angles were not similar for swim bench exercise and swimming. In addition, the three-dimensional movement pattern in the water cannot be reproduced on the swim bench. In this investigation, no siginificant correlation was found between swim bench strength and swim performance (Tanaka et al., 1993).

A study by Hsu et al. (1997) found that the outer and inner rotation strength exercises via isokinetic exercise machines which directly affect the rotator cuff muscles to increase swim velocity and overall propulsion of the swimmer. In addition, the improved endurance and power of knee and shoulder joints using specific isokinetic training at 180 and 240 degrees per second were strongly correlated with swimming records of swimmers.

Figure 2. Biokinetic swim bench (Vasa Trainer Pro SE, http://vasatrainer.com/vasa-trainer.html).

2.4. Ergometer swim bench training

Dry-land training includes specifically structured strength training program performed usually with the resistance of the swimmer's body. Training sessions are often assisted by specific apparatus including ergometers for swimming paddling (Figure 3) as well as cycle ergometers. These devices allow to improve the swimming performance in spite of the swimming drag. They offer an alternative for overloading an athlete especially under maximal velocity conditions. The ability to perform movements with high speed is represented by muscle power (Sadowski et al., 2012).

In Sadowski et al. (2012) study, the power training program on land using the ergometer lasted six weeks (18 sessions). Training sessions were held three times a week (Monday, Wednesday and Friday) before training in the water which was preceded by a 10-minute warm-up. Training sessions using the ergometer consisted of 6 sets of 50 seconds of work with rest intervals of 10 seconds. In this research the experimental group tended to present slightly greater improvements in sprint performance. The stroke frequency insignificantly decreased (-4.30%, $p>0.05$) in the experimental group and increased (6.28%, $p>0.05$) in the control group. The distance per stroke insignificantly increased in the experimental group (5.98%, $p>0.05$) and insignificantly decreased in the control group (-5.36%, $p>0.05$). A significant improvement of tethered swimming force for the experimental group was found (9.64%, $p<0.02$), whereas the increase was not statistically significant in the control group (2.86%, p>0.05). The main data cannot clearly state that power training allowed an enhancement in swimming performance, although a tendency to improve swimming performance in tethered swimming was noticed (Sadowski et al., 2012).

Figure 3. Ergometer swim bench (Vasa Swim Ergometer, http://vasatrainer.com/vasa-trainer.html).

2.5. In-water assisted- and resisted-sprint training

Girold et al. (2006) undertook a study to determine whether the resisted-sprint in overstrength (OSt) or the assisted-sprint in overspeed (OSp) (Figure 4) could be efficient training methods to increase 100m front crawl performance. Thirty-seven (16 men, 21 women) competition-level swimmers (mean ± SD; age 17.5 ± 3.5 years, height 173 ± 14 cm, weight 63 ± 14 kg) were randomly divided into 3 groups; swimmers in the OSt group swam 6 all-out 30-second front crawl sprints with a 30-second recovery period between each sprint with the total duration of 6 minutes. The swimmers were fastened to the starting platform, wearing a belt around the pelvis that was attached to one end of a 5-m-long elastic surgical tube (inner and outer diameters 8 and 12 cm, respectively); the other end of the elastic tube was attached to the starting platform (Figure 4). The elastic tube stretched over an average distance of 15 m. During the recovery, the swimmers held onto the swimming lane to keep the tube taut, swimmers in the OSp group swam 12 25m freestyle front crawl sprints. These swimmers were also attached to an elastic surgical tube under the same conditions as for OSt except that the tube was 8m long and attached to the point of arrival. The point of departure was set at the 25m line so that the elastic tube pulled the swimmer toward the point of arrival with an initial force of 60 N. As the swimmer advanced, an assistant maintained the elastic tube as taut as possible to maintain the same force throughout the sprint. The swimmers were asked to follow the speed given by the elastic tube by having a high stroke rate and trying to not decrease their distance per stroke. Between each sprint, the swimmer got out of the pool, walked back to the point of departure, and jumped into the water. This walk back was considered as a recovery period so the total duration was about the same as for the OSt group about 6 minutes and control group (C) swam 6 50m all-out front crawl sprints, without an elastic tube, with a 30-second recovery period between sprints, for a total duration of about 6 minutes. All swimmers trained 6 days per week for 3 weeks, including 3 resisted or assisted training sessions per week for the groups OSt and OSp respectively. Elastic tubes were used to generate swimming overstrength and overspeed. Three 100m events were performed before, during, and after the training period. In the OSt group, elbow extensor strength, swimming velocity, and stroke rate increased significantly ($p<0.05$), while stroke length remained unchanged after the 3-week training period. In the OSp group, stroke rate increased significantly ($p<0.05$) and stroke length decreased significantly ($p<0.05$) without changes in swimming velocity. No significant variations in the C group were observed. Both OSt and OSp proved to be more efficient than the traditional training program. However, the OSt training program had a larger impact on muscle strength, swimming performance, and stroke technique than the OSp program (Girold et al., 2006).

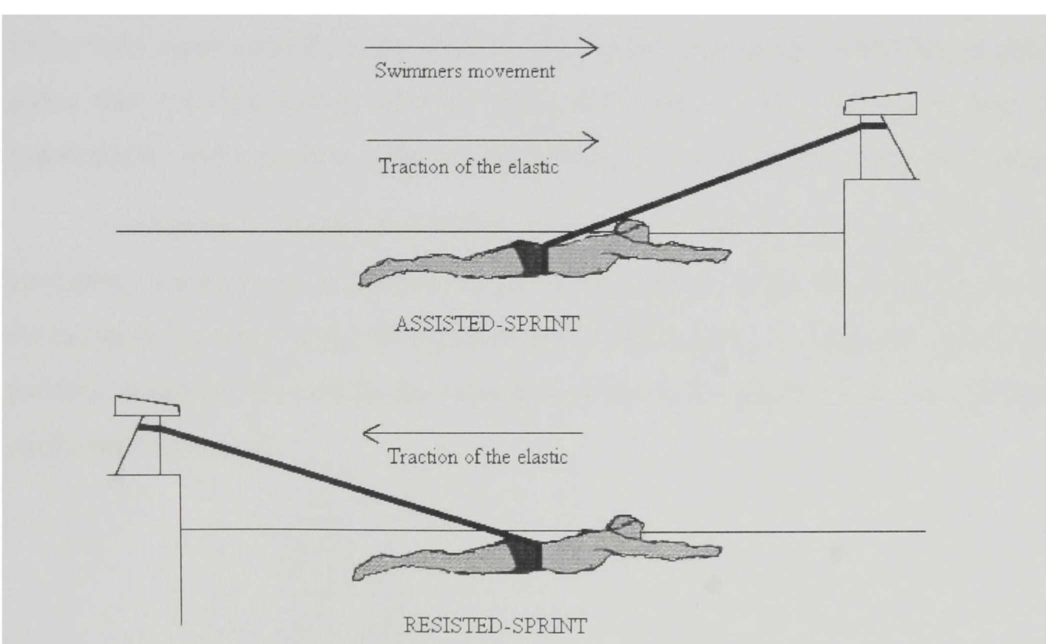

Figure 4. View of the swimmers situations during the exercises in assisted- and resisted-sprint (Girold et al., 2006).

2.6. Swimming training with hand paddles

Hand paddles are used in swimming training as a tool to increase the strength of the swimmer's arms. Hand paddles increase the propulsive area of the hand and the swimmer has to push against a greater mass of water in each stroke and his hands have to overcome a greater resistance than in free swimming. Hand paddle swimming causes an increase in the duration of the underwater pull and in the total stroke duration, in comparison with free swimming. However, the magnitude of these increases depend on the size of the paddles (Gourgoulis et al., 2008). Hand paddles are effective when they do not cause significant modifications on the hand movement pattern and do not change the kinematic characteristics of the underwater stroke. The influence of hand paddles of various sizes in specific kinematic characteristics was explored in López-Plaza et al. (2012) study. The stroke length is the kinematic parameter which is affected most strongly by the use of hand paddles. The velocity in the second 50m wearing hand paddles was significantly higher than in the no paddle condition because of an increase in stroke length, whereas the stroke rate showed a slight negative trend with increasing paddle size. The influence of the start and turn was smaller than in previous study by Gourgoulis et al. (2008) because the tests were conducted over a 100m distance in a 50m swimming pool (López-Plaza et al., 2012). On the contrary, previous study done by Sidney et al. (2001) found that the relative duration of the push phase was significantly increased. Payton and Lauder (1995) found significant increases in the durations of the total underwater pull, the glide phase and the push phase, while the duration of the pull phase was not significantly altered. Ogita and Tabata (1993) found also that training with hand paddles had a positive effect on swimming performance by increasing stroke efficiency.

According to Maglischo (2003), training with hand paddles is effective only when the swimming velocity and the stroke length are increased, while the stroke rate is kept close to the competition rates. In the Gourgoulis et al. (2008) study, it was found that as the size of the paddles increased, the swimming velocity and the stroke length were also increased, while the stroke rate decreased.

3. STRENGTH AND POWER TRAINING PROGRAMS FOR FRONT CRAWL SWIMMERS

Strength and power training programs for front crawl swimmers have to increase the characteristics of muscle forces which are transfered into improved swimming times. Strength, power and muscular endurance training both lead to physiological adaptations, improved biomechanics, and reduced risk of shoulder related injuries. The programs (Table 2) from the study (Sortwell, 2012) are designed to meet the goals of developing both strength and power while also reducing injuries. To effectively meet these goals the program is shown in the Tables 3 and 4. The exercises chosen for the front crawl swimmers develop muscle groups and joint actions used in front crawl (Table 1 and appendixes 1, 2). The chosen exercises target and emphasize the lower body, deltoids, latissimus dorsi, triceps brachii, shoulder region and pelvic, trunk area. There are four sessions in the program. The program includes sessions one and three which focus on maximal strength and sessions two and four which focus on power. With this program three sessions are completed per week alternating between maximal strength and power sessions, with at least one day rest between workouts (Table 4). Two to three weekly sessions of maximal strength training are sufficient to improve maximal force in front crawl swimming (Sortwell, 2012).

Table 2. Resistance training program – maximal strength and power transition phase (Sortwell, 2012).

Session	One	Two	Three	Four
Stage	Maximal strength	Power	Muscular strength	Power
Exercises	Dead lift	Squat jumps*	Squats	Power cleans*
	Chin-ups with weight	Timed chin ups	Seated rows - single arm	Single arm lat pulldowns
	Leg extension	Leg curls	Dumbbell press	Single leg press
	Dumbbell bench press	Incline bench press	Single arm straight arm pulldowns	Reverse flies
	Side raises	Dumbbell upright rows	Reverse hyper-extensions	One arm biceps curls
	Pullovers and press	Close grip push ups on medicine ball*	Shoulder press	Sled work*
	Rotator cuff routine (see below)	Wrist curls	Rotator cuff routine (see below)	Supine medicine ball chest pass*
	Abdominal machine	Straight arm medicine ball throw downs* Roman chair - with static holds	Weighted abdominals sit-ups	Single leg v sit-ups
Supplementary routines				
Control / stability routine	Swiss stability log roll in horizontal position	Diagonal chops with cable machine	Rainbow abdominal twist with medicine ball	Swiss ball bridge with medicine ball drop
Rotator cuff routine	Lying side external dumbbell rotation or standing thera-band external rotation	Standing frontal theraband or dumbbell rotations	Lying frontal dumbbell rotator cuff	Body-blade internal/ external rotation, front raise and lateral raise positions

*Power: 30-70% intensity of 1 RM.

Table 3. Framework for types of resistance training (Sortwell, 2012).

Type	Reps	Sets	Lifting speed	Intensity	Rest
Maximal strength	1-6	3-4	Moderate	85-100%	2-5 min
Maximal power	2-4	3-4	Explosive, fast	Strength: 90-100% Power: 30-70%	2-5 min
Hypertrophy	8-12	3-6	Slow to moderate	65-80%	30-90 sec
Strength/ power endurance	10-20	3-6	Moderate	45-65%	15-60 sec
Control/ stability	5-20*	3-6	Slow to medium to fast*	45-65%	30-60 sec

*Increase repetitions (reps) and speed when stability and control improves.

Table 4. Weekly training schedule of sessions (Sortwell, 2012).

	Session	Session	Session
Week 1	One	Two	Three
Week 2	Four	One	Two
Week 3	Three	Four	One
Week 4	Two	Three	Four

The resistance training program also include supplementary training routines (Table 2), which develop rotator cuff and core strength. Development of muscular endurance core strength is important because swimmers must maintain stability and support their body in the unstable environment for long periods of time while training. Stability and control needs to be a part of each strength training sessioon. Trunk strength is critical because all movements originate through the trunk and trunk rotation is necessary for body roll, efficiency of the stroke and injury prevention (Sortwell, 2012).

Each session includes exercises which progress from large to small muscle groups, alternating upper and lower body parts to rest and recover from the exercise (Sortwell, 2012).

The program consists of exercises which effectively increase muscle power rather than predominantly strength. These exercises are performed in an explosive manner, which involve rapid development of force. Weightlifting movements such as the power clean are appropriate as well as a range of dumbbell exercises which can be executed with a greater amount of power. Furthermore to purposely improve the upper body actions of front crawl, use of medicine balls can be thrown to enhance power development and rate of force development (Sortwell, 2012).

Lower body strength and power is important for the start, leg kick quantity per stroke, stabilisation, stroke length and turning. Therefore cleans and various types of squats form the basis of the leg training (Sortwell, 2012).

Session one of the resistance training program is a maximum strength day combined with muscular endurance for the prevention rotator cuff injuries. Session two of resistance training includes focuses on power with ballistic movements, for example timed chin-ups. In session two medicine ball ballistic movements replicate the midpoint pull through, to improve the time component of power. Session three focuses on muscular strength and rotator cuff injury prevention. Session four focuses on power with the main purpose of training the force component of power. Control stability training is performed as part of the warm-up before each resistance training session building up to higher repetitions as stability and control improve. The goal of stability and control training is to improve ability to maintain proper posture, balance, and alignment in the water which also results in improving ability to maintain efficient technique throughout the entire front crawl event. Lower abdominal strengthening is emphasized in stability and control supplementary routine, to prevent excessive anterior pelvic tilt and lumbar lordosis (Sortwell, 2012).

Because elite swimmers race throughout the whole year, nonlinear or undulating loading pattern has been used which addresses the regular schedule of competition (Table 5 & 6). The program (Table 2) involves a variety and this provides a frequent change in neural stimulation. The frequent changes in that stimulation (loads, intensities, exercises) is thought to be highly beneficial for strength gains (Stone et al., 2003). The combined benefit of the undulating model of 1RM and the design of the program is that it allows for sufficient recovery between similar sessions while preventing detraining (Sortwell, 2012).

Table 5. Undulating cycling intensity and load for maximal strength development (Sortwell, 2012).

Cycle	Reps	Set	Lifting speed	Intensity	Rest
1	6	3	Moderate	85%	2 min
2	2	4	Moderate	95%	4 min
3	4	4	Moderate	90%	2-3 min

Table 6. Undulating cycling intensity and load for power development (Sortwell, 2012).

Cycle	Reps	Set	Lifting speed	Intensity	Rest
1	3	3	Fast	90%	3 min
2	3	4	Explosive	90%	4 min
3	2	4	Fast	95%	4 min

The effect of a combined intervention of maximal strength training and high-intensity interval training on swimming performance and performance-related parameters such as swimming force, maximal velocity, swimming economy and maximal oxygen uptake (Aspenes et al., 2009). A combined intervention of strength and endurance training is common practice in elite swimming training, but the scientific evidence is scarce. Aspenes et al. (2009) examined a combined intervention of maximal strength – the strength training consisted of five maximal repetitions for three series with initial maximal mobilization of force in the concentric action and a slow eccentric phase at one side of a cable crossover apparatus; thereby primarily engaging the latissimus dorsi, triceps brachii and the rotator cuff; all of which are important in front crawl swimming. Preceding the strength training a 5-10 minute cardiovascular warm-up on either an ergometer bike, a treadmill or by swimming was carried out. In addition, a specific warm-up procedure using 10-15 repetitions of 50-80% of 1RM on the strength training apparatus was performed before the intervention training and high aerobic intensity interval endurance – the endurance training was carried out in front crawl swimming in a 25m pool, preceded by a warm-up of 20-40 minutes. Aspenes et al. (2009) used in their study a study done by Helgerud et al. (2007) where training regimen of 4 × 4 minute were carried out at 90-95% of individual HR_{max} by three minute 60-75% of individual HR_{max}. Two training sessions per week over 11 weeks in addition to regular training were used, while the control group continued regular practice. Aspenes et al. (2009) found that the intervention group improved land strength, tethered swimming force and 400m freestyle performance more than the control group (Tabel 7). The improvement of the 400m was in correlation with the improvement of tethered swimming force in the female part of the intervention group. No changes occurred in stroke length, stroke rate, performance in 50m or 100m, swimming economy or peak oxygen uptake during swimming. Two weekly dry-land strength training sessions for 11 weeks increased tethered swimming force in competitive swimmers and it was thus concluded that strength training might be important for improving middle distance swimming. This increment further improves middle distance swimming performance. Two weekly sessions of high-intensity interval training did not improve peak oxygen uptake compared with other competitive swimmers (Aspenes et al., 2009).

Table 7. Swimming force, dry-land strength, swimming performance times, maximal velocity, stroke length and stroke rate (all data are presented as mean standard deviation) (Aspenes et al., 2009).

		Intervention group				Control group			
		All (n = 11)		Female (n = 5)		All (n = 9)		Female (n = 7)	
F_S (N)	Pre	124.9	(23.2)	109.8	(6.9)	114.4	(17.3)	107.0	(4.7)
	Post	133.5	(21.9)**†	117.8	(6.7)*†	118.1	(18.3)†	109.3	(3.4)†
F_L (N)	Pre	318.8	(89.8)	260.0	(32.9)	277.9	(44.2)	262.8	(36.7)
	Post	383.5	(89.3)**†	323.7	(32.0)*	310.7	(56.2)*†	287.3	(33.8)*
50m (s)	Pre	28.88	(2.00)	30.51	(1.43)	29.35	(1.72)	29.87	(1.48)
	Post	28.55	(1.80)	29.93	(1.40)	29.16	(1.76)	29.83	(1.35)
100m (s)	Pre	63.00	(4.12)	66.52	(2.95)	64.08	(4.18)	65.43	(3.50)
	Post	62.05	(3.82)	64.75	(3.42)	64.06	(4.80)	65.78	(3.87)
400m (s)	Pre	290.43	(16.26)	301.83	(15.02)	290.08	(16.20)	294.70	(14.88)
	Post	286.43	(16.64)*	298.09	(17.56)	290.40	(18.24)	296.62	(15.50)
V_{max} ($^m/_s$)	Pre	1.59	(.11)^{10}	1.50	(.09)	1.53	(.08)^{7}	1.50	(.06)^{5}
	Post	1.60	(.10)^{10}	1.53	(.06)	1.56	(.07)^{7}	1.53	(.03)^{5}
SL (m)	Pre	1.68	(.17)^{10}	1.61	(.11)†	1.74	(.13)^{7}	1.78	(.10)^{5}†
	Post	1.73	(.16)^{10}	1.65	(.14)	1.80	(.15)^{7}	1.80	(.18)^{5}
SR (Hz)	Pre	.953	(.090)^{10}	.936	(.086)†	.885	(.078)^{7}	.846	(.036)^{5}†
	Post	.930	(.074)^{10}	.929	(.074)	.872	(.078)^{7}	.858	(.090)^{5}

F_S: Maximal swimming force, N: Newton; F_L: 1RM land strength; 50m: 50m maximal front crawl swimming, m: meters, s: seconds; 100m: 100m maximal front crawl swimming; 400m: 400m maximal front crawl swimming; V_{max}: Maximal swimming velocity; ^{10}: Include 10 subjects, ^{7}: Include 7 subjects, ^{5}: Include 5 subjects; SL: Stroke length; SR: Stroke rate; rpm: repetitions per minute (in this context stroke-cycles per minute); * Significant change in group at $p<0.05$; ** Significant change in group at $p<0.01$; † Significant difference between intervention group and control group at $p<0.05$.

Girold et al. (2007) undertook a study to compare the effects of dry-land strength training with a combined in-water resisted- and assisted-sprint program in swimmers. Twenty-one swimmers from France regional to national level participated in this study, in which they were randomly assigned to 3 groups; first, the strength (S) group, that was involved in a dry-land strength training program which first concentrated on increasing the muscular strength of the upper limbs, secondly the abdominal muscles, and thirdly the lower limbs. The upper limbs were principally the biceps and triceps brachii; the back, and the pectoral and the deltoid muscles. The lower limbs were principally the quadriceps, gluteus muscles, and calf. These strength training sessions lasted for 45 minutes; preceded by a rope-skipping warm-up of 10 minutes. The program remained the same in each strength training session: there were 3 exercises per muscular group with a rest of 2 minutes between each exercise. This program was repeated 3 times in a row per session. A maximum of 6 repetitions was realized in each exercise, except for the abdominal exercises, for which 20 repetitions were realized. The exercises for the upper limbs consisted of pressing, pulling up and drawing barbells; the weight of which was increased after every 3 weeks during the training period according to 1 repetition maximum (1RM). The exercises for the lower limbs consisted of different types of squats in addition to plyometric jumps. The intensity of the training varied between 80 and 90% of the maximal load. The subjects were instructed to perform a concentric contraction as fast as possible, followed by a 3-second isometric contraction and an eccentric resistance to return to the initial position. The rate of the exercises were 1 movement for every 6 seconds where barbells were used (Girold et al., 2007).

Second group was the resisted- and assisted-sprint (RAS) group that got involved in a specific water training program where elastic tubes were used to generate resistance and assistance while swimming (the RAS training program was fairly similar to the program which Girold et al. conducted in 2006; see in chapter 2.5.). The program was performed with elastic tubes by which the swimmers were fastened to the starting platvorm (Figure 4). They wore a belt around their pelvis'; the belt was attached to a 5.6-meter elastic surgical tube. The other extremity of the tube was attached to the starting platform. These training sessions lasted 45 minutes with a standardized warm-up of 10 minutes and consisted of 2 sets of 3 repetitions per program. 1 set was performed in front crawl and in order to make training more interesting for the athletes, 1 set was performed in their speciality with 30 seconds of rest was implemented between each repetition. This program was repeated 3 times per session and the program remained the same in each training session. Between each program, swimmers performed 200m recovery swimming. The sequence of resisted- and assisted-sprint was realized in the following manner: the swimmers first swam in resisted-sprint, until they arrived either at the mechanical stretching limit of the elastic tube (about 25m), or to their own limits, which meant swimming without moving forward. The return was performed in assisted-sprint. The elastic tube pulled the swimmer toward the point of arrival with an initial force of 60 N. During swimming, an assistant sustained the elastic tube as tight as possible, thus maintaining the same force throughout the sprint. The swimmers were asked to follow the speed given by the elastic tube by having a high stroke rate and by trying to keep their stroke distance. The variation of the exercise intensity was induced by the increase of the distance reached in resisted-sprint, and/or by the speed reached in resisted- and assisted-sprint (Girold et al., 2007).

The third assigned group was the control (C) group, which was involved in an aerobic training program (cycling and running) which was performed once a week at a low intensity (between 60 and 70% of maximal heart rate), during 45-minute and 1-hour 30-minute sessions, respectively). During 12 weeks, the athletes performed 6 training sessions per week on separate days. All of the training sessions combined the same aerobic dominant work for their basic training in swimming and running with their specific training. The outcome values were the strength of the elbow flexors and extensors evaluated using an isokinetic dynamometer, and the speed, stroke rate, stroke length, and stroke depth found during a 50-meter sprint. At the end of the training period, Girold et al. (2007) found significant increases in swimming velocity, and strength of elbow flexors and extensors both in the S and RAS groups. Stroke depth decreased both in the S and RAS groups. Stroke rate increased in the RAS but not in the S group. However, no significant differences in the swimming performances between the S and RAS groups were observed. No significant changes occurred in C. Altogether, programs combining swimming with dry-land strength or with in-water resisted- and assisted-sprint exercises led to a similar gain in sprint performance and are more efficient than traditional swimming training methods alone (Girold et al., 2007).

SUMMARY

The strength, power and injury prevention program for front crawl swimmers needs to take into consideration both physiological requirements and biomechanical aspects of the specific stroke. A successful resistance program for a front crawl swimmer should aim to improve stroke length (the length through which strength is produced) and streamlining ability (the ability to be strong and stable which allows the swimmer to hold required specific positions in the water). It is very important for swimmers to apply more force in the stroke over a longer period of time and create a good impulse rather than need to have a high stroke rate.

Strength and power training enhance leg power through which kick quantity per stroke and starting block clearance are improved and greater level of propulsion force is maintained at sub-maximal efforts. Improved core strength is a key factor for better body balance and injury prevention in swimming. This is expressed by a good body control and body roll which assist best stroke length, which is more efficent and allow to swim a greater distance with each pull.

Before designing a training program for a specific individual, the swimming coaches should consider different aspects which influence the swimmer's front crawl swimming technique: strengths, weaknesses, and previous injuries to get the optimal results. Muscle resistance training during swimming in water and specific training on dry-land has had beneficial effects on swimming records.

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RESÜMEE

Rinnulikrooli ujujate jõu ning võimsuse treening

Rinnulikrooli ujumises on ökonoomsuse üheks olulisemaks näitajaks samal ujumiskiirusel ühe tõmbe jooksul läbitud vahemaa. Tõmbe pikkus on üks tähtsamaid ujumistulemuse mõjutajaid rinnulikroolis. Tõmbe pikkus võrdub distantsi pikkus (m) jagatud tõmmete arvuga distantsil. Rinnulikrooli ujujad peavad saavutama tõmbe sageduse ja tõmbe pikkuse optimaalse suhte, et säilitada maksimaalset ujumiskiirust, sellest sõltub suurel määral sportlase võistlustulemus.

Rinnulikrooli ujujate jõu ning võimsuse arendamisele suunatud treeningprogrammid on koostatud jälgides spetsiaalselt rinnulikrooli ujumise biomehaanilisi parameetreid. Need treeningprogrammid peaksid olema üles ehitatud selliselt, et parandaksid ujujate võistlussooritust, mis hõlmab endas tõmbe sageduse ja tõmbe pikkuse suurenemist, läbi mille paraneb ka rinnulikrooli ujujate sooritus.

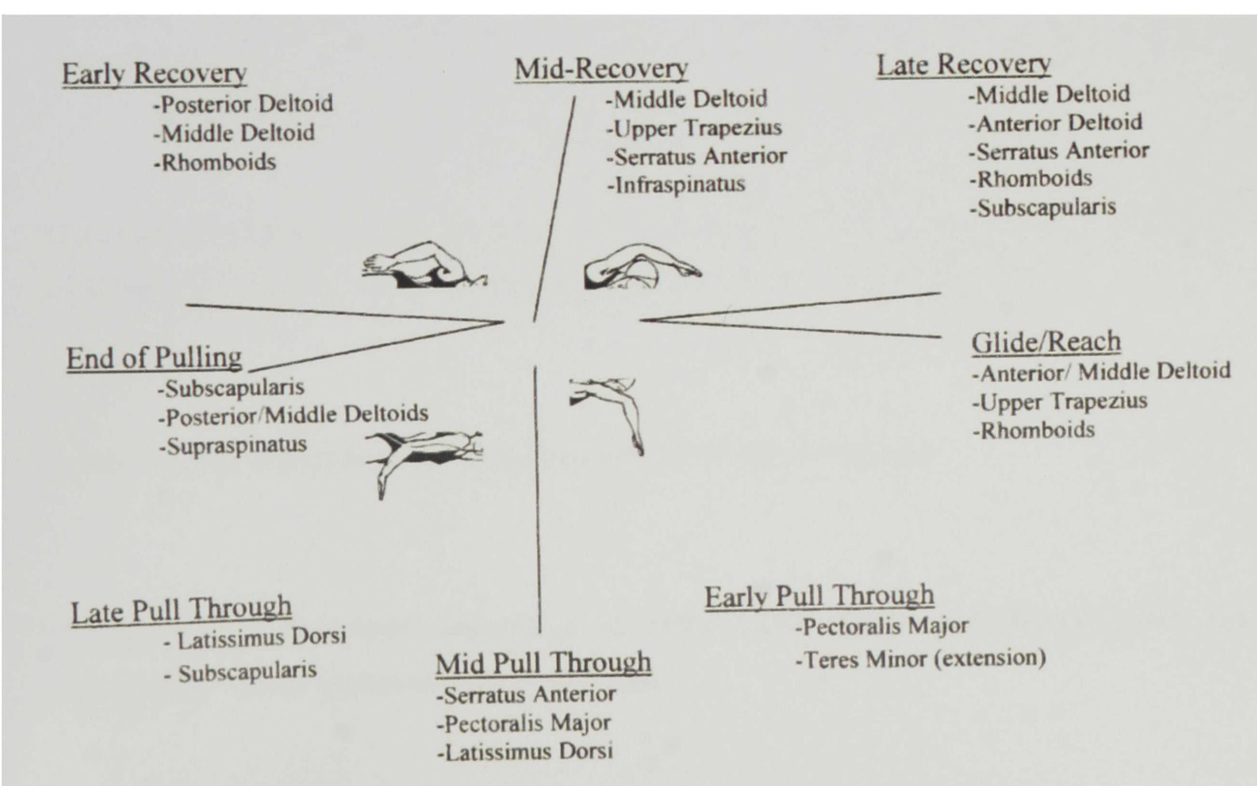
Ujujatele on veetakistuse vähendamiseks ning ületamiseks oluline hoida ja säilitada keha stabiilset ning voolujoonelist asendit veekeskkonnas, mistõttu peavad ujujad keskenduma kerelihaste jõuomaduste arendamisele. Samuti on oluline rakendada võimalikult palju lihasjõudu rinnulikrooli ujumise tõmbe soorituse tehnilistesse faasidesse ning ka jalgade töösse. Jalgade töö osakaal on ujumises järjest tõusnud. Selle olulisus määrab ära ujuja võime sooritada võimalikult efektiivselt stardihetkel äratõuget pukilt, stardist väljumist veest, pöördesse minekut ning pöördest väljumist.

Treeningplaane koostades ning treeninguid planeerides peaksid ujumistreenerid lähenema sportlastele individuaalselt, arvestades nende rinnulikrooli ujumistehnikaga seotud tugevaid ning nõrku külgi (erinevad tehnilised parameetrid ja kehalist töövõimet määravad tegurid).

APPENDIXES

Appendix 1. Active muscle groups of the front crawl swimming (McLeod, 2010).

Appendix 2. Muscle activity of the freestyle stroke based on electromyographic and cinematographic analysis (Heinlein & Cosgarea, 2010).



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