Resisted Sprint Training in Swimming

- A Quasi-Experimental Study on Swedish National Level Swimmers

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Abstract

Aim
The aim of this study was to ascertain the effect of resisted sprint training in swimming on maximal swimming velocity and performance characteristics. The aim was also to examine how maximal swimming velocity is related to maximal swim power and maximal dry-land power.

Method
Eighteen competitive national level swimmers (9 male and 9 female; age: 18.3 ± 2.3 years, body mass: 72 ± 8.3 kg, height: 177.2 ± 4.6 cm, mean ± SD) were recruited to this study. Subjects were assigned to either resisted sprint training (RST) or unresisted sprint training (UST). Sprint training was performed two times per week during 6 weeks as 8x15m with a 2min send-off interval. RST performed sprint training using individualized load corresponding 10% of maximum drag load ($L_{10}$), UST performed sprint training with no added resistance. A test-battery including dry-land strength assessment; maximal strength ($MxS$) and explosive strength ($ExS$), a timed 25m front-crawl swim and in-water force-velocity profiling was performed prior and following the training intervention. Maximal swim power ($P_{max}$), maximum drag load ($F_0$), theoretical maximum velocity ($v_0$) and slope of force-velocity curve ($S_{Fv}$) was computed though force-velocity profiling.

Results
No significant within group differences occurred in neither RST nor UST following the 6-week intervention period in: swimming velocity, $MxS$, $ExS$, $P_{max}$, $F_0$, $v_0$, and $S_{Fv}$.
Strong correlations were found between swimming velocity and $MxS$ ($r = 0.75$), $ExS$ ($r = 0.82$) and $P_{max}$ ($r = 0.92$).

Conclusion
Resisted sprint training in swimming using $L_{10}$ did in the present study not elicit any improvements in maximal swimming velocity or examined performance characteristics. Resisted sprint training does not appear to be a superior method of improving swimming performance compared to unresisted sprint training. $MxS$, $ExS$ and $P_{max}$ can be used as robust predictors of swim performance, however only $P_{max}$ was found to be casually related to swimming velocity.
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Abbreviation Dictionary

$C_D$ – hydrodynamic force coefficient
$ExS$ – dry-land explosive strength
$e_g$ – gross efficiency
$e_p$ – propelling efficiency
$F_p$ – propulsive force
$F_d$ – drag force
$F_{-v}$ – force-velocity
$F_0$ – theoretical maximum force (maximum drag load)
$L_{10}$ – load corresponding 10% of maximum drag load
$L_{opt}$ – load corresponding to maximal power output
$MxS$ – dry-land maximal strength
$P_d$ – power to overcome drag (useful power)
$P_k$ – power lost in giving water kinetic energy
$P_i$ – power input (metabolic power)
$P_{max}$ – maximal swim power
$P_o$ – mechanical power output
$RST$ – resisted sprint training
$SI$ – stroke index
$SL$ – stroke length
$SR$ – stroke rate (stroke frequency)
$S_{Fv}$ – slope of force-velocity curve
$UST$ – unrestricted sprint training
$v_0$ – theoretical maximum velocity
$\Delta%$ – delta in % (change in %)
# Table of Contents

1 Introduction .................................................................................................................................................. 1  
2 Purpose ..................................................................................................................................................... 7  
3 Method ........................................................................................................................................................ 7  
   3.1 Design .................................................................................................................................................... 7  
   3.2 Subjects ................................................................................................................................................. 7  
   3.3 Equipment ............................................................................................................................................ 9  
   3.4 Testing Procedure .................................................................................................................................. 9  
      3.4.1 Dry-land Strength & Power ............................................................................................................. 10  
      3.4.2 Swim Performance ......................................................................................................................... 11  
      3.4.3 Force-velocity Profiling ................................................................................................................ 12  
   3.5 Training Intervention .......................................................................................................................... 14  
   3.6 Statistical Analysis ............................................................................................................................. 15  
4 Results .......................................................................................................................................................... 16  
5 Discussion .................................................................................................................................................... 22  
   5.1 Training Intervention .......................................................................................................................... 22  
   5.2 Dry-land Strength & Power .................................................................................................................. 23  
   5.3 Predictors of Swimming Velocity ....................................................................................................... 24  
   5.3 Force-velocity Profiling ....................................................................................................................... 25  
   5.3 Interpretation of F-v Profiling and Dry-land Strength ...................................................................... 26  
   5.4 Conclusion .......................................................................................................................................... 27  
References ...................................................................................................................................................... 28  

Appendix 1: Informed Consent  
Appendix 2: Test Protocol  
Appendix 3: Warm-up Protocol
1 Introduction

Swimming is one of the nine original sporting events that has been part of the Olympic program since the start of the modern Olympic Games in Athens 1896. Comprised of thirteen individual and three relay events for men and women respectively, swimming is nowadays the largest Olympic sport with regard to available medals. Swimming performance is influenced by anthropometrical, technical, tactical, physiological and psychological determinants (Wallberg 2013). Most of these determinants remain relatively unchanged, whereas the physiological requirements differ substantially depending on the duration of the event. Long distance events such as the 1500m depend almost solely on aerobic energy supply. Top-level performance in events with high aerobic demand is characterized by high VO$_{2\text{max}}$, high lactate threshold velocity and good swimming economy (Basset & Howley 2000). 50m sprint events on the other hand rely mainly on anaerobic metabolism and demand large amounts of power output during approximately 20-25s (Rodriquez & Mader 2010).

Strong correlations have been found between anaerobic power output and maximal swimming velocity. Power is defined as the product of force and velocity and can be measured using both in-water and dry-land methods in swimming (Dominquez-Castells, Izquioerdo & Arellano 2013). Considering that the arms generate the majority of the propulsive forces during free swimming (Deschotd, Arsc & Rouard 1999) dry-land power measurements are traditionally made using the upper body. Power output attained during arm cranking in upper body ergometers has been shown to correlate strongly ($r = 0.83$ & $r = 0.63$) with maximum swimming velocity (Hawley & Williams 1991; Hawley et al.1992). Dry-land power output in swimming is however more commonly measured using biokinetic swim benches. A swim bench mimics the arm stroke kinetically by allowing acceleration throughout motion. Consequently, power output measured in swim benches generally elicit higher correlations with swimming velocity than upper body ergometers. Sharp, Troup & Costill (1982) found a strong relationship ($r = 0.90$) between swim bench power output and 25-yard freestyle velocity. In a similar study, 25y freestyle velocity was found to correlate ($r = 0.74$) with swim bench power output (Johnson, Sharp & Hedrick 1993).

Intervention studies have in some cases shown that power output is causally related to swimming velocity over sprint distances, i.e. when power output increases, swimming velocity increases as well (Sharp, Troup & Costill 1982). Contradictory to these findings...
Toussaint & Vervoorn (1990) found that power output, measured using the Measuring Active Drag System (MAD-system), did not have a causal relationship with swimming velocity. Roberts et al. (1991) found similar results when examining if swim bench training is an effective way of increasing power output. Following a ten-week training intervention, no significant differences were observed between pre and post-testing power output values, measured in a biokinetic swim bench, in neither the experimental nor the control group. However, both groups improved their 100y freestyle performance, indicating that improvements in swimming velocity can take place without increased power output. A reasonable explanation to these finding would be improved swimming technique.

Technique is the single most important determining factor to swim performance (Wallberg 2013). Swimming velocity is kinetically determined by a combination of propulsive force \( F_p \) i.e. force created to move the body forward and drag force \( F_d \) i.e. resistive force acting in the opposite direction. Swimming velocity can therefore be defined as following (Toussaint & Beek 1992):

\[
F_p(v) - F_d(v) = mv
\]

Drag force is affected by hydrodynamic drag coefficient \( C_D \), density of the water \( p \), velocity \( v \) and frontal surface area of the object \( A \). Drag force can be calculated as (Sacilotto et al.2014):

\[
F_d = \frac{1}{2} C_D p v^2 A
\]

Improved swimming velocity can therefore take place by increasing propulsive force or decreasing drag force. However, considering that drag force is related to the square of the swimming velocity, at high velocities, reducing drag takes priority over increasing propulsion. It has been shown that highly skilled swimmers create less drag at high velocities than less skilled swimmers (Toussaint et al.1990).

When measuring drag force \( F_d \) a distinction is made between active drag and passive drag. Active drag is the resistive force associated with dynamic swimming, whereas passive drag is the resistive force a human body experiences in a static position (Sacilotto et al. 2014). Active
drag can be measured directly through the Measuring Active Drag-System (MAD-system), which operates with fixed push-off pads mounted under the surface of the water. The push off-pads are used to generate propulsion when swimming and are connected to a force transducer allowing computation of active drag (Hollander et al. 1986). Active drag can also be estimated through Velocity Perturbation Method (VPM), which involves performing two swim trials with maximal intensity. One trial is performed as free swimming while the other is performed towing a hydrodynamic body creating a known resistance. The two trials are analyzed with the equal power assumption, where the difference in swimming velocity is attributed to the added resistance created by the hydrodynamic body, allowing calculation of active drag (Kolmogorov & Duplishcheva 1992). Although the two methods are commonly used to determine active drag, they have been found to produce significantly different results (Toussaint, Roos & Kolmogorov 2004).

Komogorov & Duplishcheva (1992) examined active and passive drag values in Soviet national-team swimmers and found that large variations in active drag values exist even among top-level swimmers. Additionally, highly skilled swimmers can in some cases display lower active drag values than passive drag values. Active drag is largely influenced by swimming technique while passive drag is affected by individually anthropometry and streamlining ability. When measuring active drag with VPM, a hydrodynamic force coefficient ($C_D$) can be attained. $C_D$ can in turn be used as a quantitative measure of technique, where low values indicated efficient swimming technique. (Komogorov & Duplishcheva 1992)

Stroke index ($SI$) is another way of objectively quantifying swimming technique without calculating drag. In this method swimming velocity [m·s$^{-1}$] is defined as the product of stroke rate ($SR$) and stroke length ($SL$). $SR$ is the amount of stroke cycles completed per unit time [s] and $SL$ is the distance covered per cycle [m]. (Smith, Norris & Hogg 2002) Although, increased swimming velocity can be achieved by increasing $SR$, $SL$ or both, Kennedy et al. (1990) found that $SL$ is the determining performance characteristic among Olympic swimmers. While most Olympic swimmers maintain fairly similar $SR$’s over set distances, interpersonal performance variations can be explained by differences in $SL$. Consequently, $SL$ is incorporated when calculating $SI$. $SI$ can be calculated as: $v^2 \cdot SL$, and be used as a simple measure of swimming technique or swimming efficiency (Rudolph et al. 2014, s.177).
Although SI is a simple and practical method of estimating swimming technique, calculating power output, active drag and hydrodynamic force coefficient produces a better and more detailed insight of the swimming technique. Mechanical power output ($P_o$) is the sum of power to overcome drag ($P_d$) and power lost in giving water kinetic energy ($P_k$) (Toussaint et al. 1988).

$$P_o = P_d + P_k$$

The ratio of useful power ($P_d$) i.e power to overcome drag to the total power output ($P_o$) is defined as propelling efficiency ($e_p$).

$$e_p = \frac{P_d}{P_o}$$

Mechanical power output ($P_o$) is in turn affected by the power input ($P_i$), which is the combined ATP-production of aerobic and anaerobic systems, often termed metabolic power. The ratio of power output ($P_o$) to the power input ($P_i$) is defined as gross efficiency ($e_g$).

$$e_g = \frac{P_o}{P_i}$$

It now becomes clear that the useful power ($P_d$) is determined by a combination of propelling efficiency ($e_p$), power output ($P_o$), gross efficiency ($e_g$) and power input ($P_i$). (Toussaint & Beek 1992)

$$P_d = e_p \cdot P_o = e_p \cdot e_g \cdot P_i$$

Assuming that active drag, gross- and propelling efficiency remain constant, increasing power input results in increased useful power and therefore increased swimming velocity. Dry-land strength and power training aims at increasing power input. Studies have shown that dry-land strength training can be used to increase swimming performance over sprint distances (Strass 1986; Girold et al. 2007). Although in-water power output was not measured in these studies, a reasonable explanation to increased swimming velocity would be increased power input without changes in propelling and gross efficiency. On the contrary, Tanaka et al. (1993) found that eight weeks resistance training did not elicit any additional increase in swimming velocity over 25y compared to only swimming. In this study, both the control and intervention
group increased their swim bench power output, despite this, no changes in swimming velocity occurred in neither of the groups. It was concluded that dry-land resistance training needs to be highly specific in order to elicit positive transfer to swimming performance.

Resisted sprint training in swimming is a commonly used training method for increasing sprinting ability. The method involves swimming with an added resistance and is considered to be swim specific strength training. The resistance can be created in various ways including elastic tubes, power racks and hydrodynamic bodies such as parachutes or sponges. Resisted sprint training is often termed over-strength training and has been shown to be an effective way of increasing swimming velocity (Girold et al. 2006; Girold et al. 2007). Increased swimming velocity could in these studies be explained by increased SR and maintained SL. Assisted sprint training on the other hand, often termed over-speed training has also been shown to increase SR while decreasing SL and therefore not improving swimming velocity (Girold et al. 2006). Resisted sprint training and dry-land resistance training have been found to elicit similar positive effect on sprint performance, where increased swimming velocity can be explained by increased upper body strength (Girold et al. 2007).

Due to the flexible nature of elastic tubes, the resistance created by the tubes increases in relation to increased displacement from the starting position. In practice, this mean when performing resisted sprints with elastic tubes the resistance will be low at the initial phase of the sprint and increase progressively throughout the sprint. Power racks on the other hand, provide isotonic resistance throughout a sprint regardless of the position of the swimmer. Although power racks are widely used, especially in the United States, evidence of its performance enhancing effects is limited. Research has shown that resisted sprinting using power rack devices have no effect on neither acute nor long terms sprinting ability (Santos-Garcia et al. 2013; Gonzalez-Rave et al. 2018; Kojima et al. 2018).

Resisted sprint swimming has in early research been shown to have detrimental effect on stroke mechanics (Maglishco et al. 1985). A number of kinematical alternations can be noted when using resistive devices creating large resistance and thereby affecting the swimming velocity. Resisted butterfly sprinting has been shown to evoke decreased hand depth, variations in elbow flexion at mid-stroke (i.e. pull and push-phase) and increased wrist flexion (Maglishco et al. 1985). Decreased hand depth has also been observed during resisted freestyle sprinting (Williams, Sinclair & Galloway 2001). These measurement have however
been performed during resisted swimming meaning that the detrimental effects do not necessarily remain once the resistance is removed. Despite these findings it is recommended that in order to optimize transfer from resisted to free swimming, stroke mechanics of free swimming should be maintained as much as possible (Maglischo et al. 1985).

Maglischo et al. (1985) recommendations of performing specific resisted sprints that maintain similar stroke mechanics of free swimming could instinctively be performed using light resistance. However, the limited amount of research in this field has either been performed with elastic tubes, which are known to create progressively increasing resistance (Girold et al. 2006; Girold et al. 2007) or with power racks using high loads and therefore probably creating large detrimental effect on stroke mechanics. In previous experimental studies, loads corresponding 70-80 % and 35-40 % of maximum load were used respectively (Gonzalez-Rave et al. 2018; Kojima et al. 2018). On the other hand, in resisted sprint running, loads 10 and 50 % of maximum load are commonly used to improve sprinting ability (Cross et al. 2018). Force and velocity have been shown to have a linear relationship, where 10 % of maximum load corresponds to 10 % decrease in unresisted running velocity (Cross et al. 2017). Sprint running performed with a load creating 10 % decrease in running velocity ($L_{10}$) is believed to increase ground reaction force when running near or at maximum velocity. Higher load corresponding to 50 % decrease in running velocity ($L_{opt}$) implies training at maximum power output. $L_{opt}$ training has recently been hypothesized to elicit greater improvements in force and power output compared to $L_{10}$, and thereby be a more effective way of enhancing the acceleration phases in running. (Cross et al. 2018)

Contrary to Cross et al. (2018) hypothesis that $L_{opt}$ would be a superior method of increasing sprinting ability over shorter distances, $L_{10}$ was found to elicit similar improvements in sprint velocity over 5, 10 & 20m. The effect of resisted sprint training in swimming using light loads as $L_{10}$ has yet to be examined. Although earlier studies suggest that resisted sprint swimming can be used effectively for increasing power input (Gonzalez-Rave et al. 2018), lacking transfer to free swimming has been attributed to detrimental effects on stroke mechanics and swimming technique. It would therefore be of interest to examine if resisted swimming using individualized $L_{10}$ can enhance swimming performance, where increased strength and power could be transferred to free swimming.
2 Purpose

The purpose of this study was to ascertain the effect of resisted sprint training in swimming on maximal swimming velocity and performance characteristics. The aim was also to examine how maximal swimming velocity is related to maximal swim power and maximal dry-land power. The following research questions were adopted:

– What effect does 6 weeks resisted sprint training in swimming have on 25m swimming velocity, maximal swim power, theoretical maximum force, theoretical maximum velocity, slope of force-velocity curve and maximal dry-land power?
– How does 25m swimming velocity correlate with maximal swim power and maximal dry-land power?
– Is maximal swim power and maximal dry-land power causally related to 25m swimming velocity?

3 Method

3.1 Design

A quasi-experimental design was conducted to ascertain the effect of resisted sprint training in swimming. Tests were performed prior and following a 6-week intervention period. Subjects were assigned to either resisted sprint training (RST) or unresisted sprint training (UST) and matched for: gender, age, 25m swimming velocity, training volume and FINA-points.

3.2 Subjects

Eighteen competitive national level swimmers (9 male and 9 female; age: 18.3 ± 2.3 years, body mass: 72 ± 8.3 kg, height: 177.2 ± 4.6 cm, mean ± SD) were recruited to this study. Participants were recruited from six different swim clubs in the Stockholm area with regard to performance level. All subjects had at least seven years’ experience of competitive swimming.
Subjects were informed verbally and in writing regarding the study’s purpose, procedures and potential risks [see Appendix 1]. All participants gave their written informed consent to participate in the study.

A lower limit of 700 FINA-points was set for participation in order to ensure elite level of the subjects. However, this lower limit was later adjusted to 600 FINA-points in order to recruit enough participants. The FINA-points table allows comparison among different events, where every event’s bestime ($B$) corresponds to 1000 points and is determined once every year to the current world record. FINA-points for a swim time ($T$) is calculated as: $(B / T)^3 \cdot 1000$ (Svenska Simförbundet). At the Swedish National Championship in Swimming, the eight fastest swimmers from the qualifying round advance to the final, the eight-time to the final generally corresponds to approximately 700 FINA-points.

Subjects were assigned to RST or UST following pre-testing and matched in order to attain as equal group means as possible for gender, age, 25m swimming velocity, total training volume and FINA-points in their best event. Subjects had to attend a minimum of 8 of the 12 sprint sessions available in order to be included in the study.

Table 1 – Descriptive statistics of groups at baseline.

<table>
<thead>
<tr>
<th></th>
<th>RST ($n = 9$)</th>
<th>UST ($n = 9$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td>4 male, 5 female</td>
<td>5 male, 4 female</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>18.4 ± 2.6</td>
<td>18.5 ± 2.0</td>
</tr>
<tr>
<td><strong>Body mass [kg]</strong></td>
<td>68.3 ± 7.5</td>
<td>76.3 ± 8.2</td>
</tr>
<tr>
<td><strong>Height [cm]</strong></td>
<td>175.8 ± 3.5</td>
<td>178.7 ± 5.6</td>
</tr>
<tr>
<td><strong>Swim velocity [m·s$^{-1}$]</strong></td>
<td>1.97 ± 0.09</td>
<td>1.97 ± 0.13</td>
</tr>
<tr>
<td><strong>Total volume [h]</strong></td>
<td>15.6 ±1.5</td>
<td>15.0 ± 2.1</td>
</tr>
<tr>
<td><strong>FINA-points</strong></td>
<td>702 ± 58</td>
<td>663 ± 41</td>
</tr>
</tbody>
</table>

Values are presented as mean ± standard deviation. Abbreviations: $n$ = sample size; kg = kilogram; cm = centimeter; m·s$^{-1}$ = meters per second; h = hours.
3.3 Equipment

Dry-land power output was measured using the swim specific apparatus: biokinetic swim bench (BioMeter®, Fahnemann; Hbg, Germany). This apparatus operates in a similar manner as an isokinetic device with the difference being that a biokinetic swim bench provides a constant amount of acceleration in proportion to the force being applied to it. A swim bench can be set to various speed setting ranging from 1-9. For a given speed setting the velocity increases with 0.005m·s⁻¹ per N of force applied and with 0.29m·s⁻¹ per speed setting, with level 9 allowing the largest speed. (Sharp, Troup & Costill 1982)

The 1080 Sprint device (1080 Motion, Lidingö, Sweden) was used for in-water power assessment and force velocity profiling. The 1080 Sprint is a portable, cable resistance device that uses a servo motor (2000 RPM OMRON G5 Series Motor; OMRON Corporation, Kyoto, Japan) to generate resistive load (Mangine et al. 2017). Mean error of the 1080 Sprint has previously been examined and shown to be low across all measurements (velocity error ± 0.5 %, distance error = ± 5mm, force error ± 4.8 N (Bergkvist, Svensson & Eriksrud 2015).

3.4 Testing Procedure

A familiarization session was performed one week prior to pre-testing. The familiarization session included three shoulder flexions in the swim bench at speed settings 1, 5, 9, respectively. Familiarization was also performed in-water with added resistance using 1080 Sprint. Participants performed three 15m swims near maximal intensity with progressive load per repetitions with ad libitum rest between trials. The familiarization was performed for the participants to get accustomed to the equipment used during testing.

Tests were performed one week prior and one week following the intervention period. Testing was carried out between 06:00–09:00 or 17:00–19:00 depending on the subject’s ability to attend the testing session and performed at the same time of day to avoid diurnal fluctuations. Subjects were asked to wear the same competition gear (i.e. swimsuit, goggles and swim cap), during pre and post-testing. The test session included: dry-land power, swim performance and swim power assessment. The session lasted approximately 90min and was performed in the above-mentioned order [see Appendix 2].
3.4.1 Dry-land Strength & Power

Dry-land power measurements were performed using Fahnemann biokinetic swim bench. After completion of a 5min dry-land warm-up [see Appendix 3] participants performed ten warm-up shoulder flexions at speed setting 5 to get accustomed to the motion prior to testing. Three maximal shoulder flexions were performed at speed settings: 1, 3, 5, 7, 9 where power data [W] was recorded. Three additional maximal shoulder flexions were performed at speed settings: 1 & 9 where work data [Nm] was obtained. Work produced at speed setting 1 is termed maximal strength (MxS) whereas work generated at setting 9 denotes explosive strength (ExS) (Rudolph et al. 2014, s.111). The single highest recorded value out of the three shoulder flexions at each speed setting was analyzed.

Participants laid down horizontally on their stomach on the swim bench with their hands attached to a paddle tied around the middle finger. Subjects were instructed to perform shoulder flexions with fairly straight arms (i.e. small elbow flexion) and to avoid the “catch” motion used during swimming. The shoulder flexions were performed with both arms simultaneously (i.e. bilateral flexion). A fully flexed arm position (i.e. beneath the waist) was used as staring position; the participants then performed three maximal shoulder flexions, from a fully extended horizontal position to a fully flexed horizontal position. This procedure was performed at every speed setting. Participants were allowed 2min passive rest between each speed setting, performed in the order 1, 3, 5, 7, 9 followed by 1 & 9.
3.4.2 Swim Performance

After completion of the dry-land power test participants performed a 1000m standardized swimming warm-up [see Appendix 3]. The participants then changed to their competition gear, this change of gear lasted approximately 10-15min allowing full recovery between warm-up and performance test. A 25m freestyle swim with maximal intensity was performed, followed by a 75m low intensity regenerative swim. This procedure was performed twice, with a combined send-off time of 3min (i.e. 25 + 75m). The 25 + 75m was completed in approximately 90s allowing 90s passive rest between the two trials. The fastest recorded time of the two 25m swims was analyzed.

The 25m swim was performed with a push-off start in order to eliminate variations in reaction time and dive-start (Costill et al. 1986). The swim was performed in a 25m pool at Eriksdalsbadet (Stockholm) and recorded in 240Hz 720p with an iPhone 7 (Apple, California, USA) using the software program Coach’s Eye (California, USA). The camera was placed perpendicular to the swimming direction in line with the starting position. The camera was then carried throughout the 25m swim and placed in line with the finishing
position of the 25m pool in order to assure accurate time acquisition. The time was initiated when the swimmer’s feet broke contact with the wall and terminated when the swimmers hand touched the wall on opposite side of the pool. Both swim trails were performed in front-crawl with maximal intensity. The swimmers were instructed to swim as fast as possible for the 25m swim and allowed 15m underwater, as allowed in competition. Swimming velocity was calculated for the entire 25m including underwater and free-swimming phase.

### 3.4.3 Force-velocity Profiling

In-water swim power was computed by force-velocity (F-v) profiling using 1080 Sprint, as the last part of the test battery. Swimmers wore the same competition gear as used during the swim performance test. The test consisted of five to six repeated freestyle sprints of 10 freestyle arm strokes i.e. 5 stroke cycles, using arms and legs, with maximal intensity. The test was initiated with a 1kg load and proceeded with 3kg increment per trial for males and 2kg increment for females. A send-off time of 3min was adopted between the sprints allowing approximately 2:50s passive rest. The test was terminated when the swimmer completed all six trials or when an average velocity of 0.5m·s$^{-1}$ could not be attained.
Mean force, velocity and power data was attained for each trial and used to compute individual F-v profiles. F-v relationships were extrapolated to obtain $F_0$ and $v_0$ as intercepts of the F-v curve as described by Samozino et al. 2015. $F_0$ is defined as the theoretical maximum force the system can generate at zero velocity and $v_0$ as the theoretical maximum velocity the system can produce at zero force (Cross et al. 2017). The slope ($S_{Fv}$) of the F-v curve was calculated as $S_{Fv} = -F_0 / v_0$ (Morin & Samozino 2016). Since in-water useful power cannot be determined using this method, swim power for each trail was calculated simply by multiplying force and velocity (Kojima et al. 2018). Maximal swim power ($P_{max}$) was computed as the highest value of a parabolic 2nd order polynomial power-velocity relationship (Cross et al. 2018). Individual $L_{10}$ for RST was determined as 10 % of $F_0$ i.e. maximal drag load. $L_{10}$ was however presented in kilograms for practical application.

Figure 2 – Graphic display of linear force-velocity relationship & polynomial power-velocity relationship (Cross et al. 2017)
Sprint was placed 3m away from the edge of the swimming pool while the cable used to tether the subjects was calibrated to 4m, this procedure was adopted during testing and training. Consequently, resistance was generated 1m away from edge of the pool. The cable used to create resistive load was attached to a harness placed around the subject’s hip. The resistance created was set to isotonic mode and placed in the first gear. Resisted speed limit was set to 10m·s$^{-1}$ whereas assisted speed limit was set to 1m·s$^{-1}$. The assisted load corresponded the resistive load for each trail. Data acquisition during testing was performed manually. Therefore, before each trial, subjects were thoroughly instructed to perform two underwater kicks following push-off and thereafter swim 10 freestyle strokes i.e. 5 stroke cycles with maximal intensity. Data acquisition was initiated flowing break-out when the subjects left hand entered the surface of the water and terminated following 3 stroking cycles, again, when the left hand entered the water.

### 3.5 Training Intervention

The training intervention was initiated one week following pre-testing and lasted 6 weeks. Subjects performed two sprint-training sessions per week in combination to their ordinary training. Sprint training was performed between 06:00–09:00 or 17:00–19:00 depending on the subject’s ability to attend the training session and performed with at least 48h between consecutive sprint sessions. The sprint sessions were initiated with 5min dry-land warm-up followed by a standardized 1000m swimming warm-up, the same warm-up used during testing (see Appendix 3). Following the warm-up, the *RST* performed 8x15m sprints with resistance corresponding $L_{10}$, while UST performed 8x15m sprints with no added resistance. Both groups were assigned 2min send-off interval allowing approximately 1:50s passive rest between each sprint, as recommended for alactic sprint training (Michalsik & Bangsbo 2004 s.178). All sprints were performed in front-crawl with a push-off start. Participants were encouraged to swim with maximal intensity and were provided with 15m swim time and stroke rate for each trail.

After completion of sprint training, subjects proceeded with their ordinary swim training. Since the participants represented various swim clubs and therefore followed different training regimes, complete standardization of all swim training was not possible. Complementary training volume is presented in table 1. Including the two sprint training sessions all subjects performed between 7-10 swimming session weekly. To minimize the
impact of the participants’ complementary training regimes, subjects were matched for weekly training volume. Training volume was quantified as total swimming hours performed weekly.

### 3.6 Statistical Analysis

Descriptive statistics were used to present participants characteristics at baseline. Statistical analyses were performed in IBM SPSS 25th Edition (SPSS, Chicago, IL, USA). Data was analyzed for normality using Shapiro-Wilks normality test. Independent T-test was used to test for between group differences at baseline for parametric data. Mann-Whitney U-test was performed as corresponding test for non-parametric data. Correlation coefficients for parametric data were calculated using Pearson Product-Moment coefficient while correlations for non-parametric data were made using Spearman’s Rank-Order coefficient. Paired Sample T-test was used to detect within group differences between pre- and post-tests for parametric variables. Wilcoxon Signed-Rank test was performed as equivalent test for non-parametric data. Confidence Intervals of 95 % were adopted in all statistical tests.
4 Results

There were no significant differences between RST and UST prior to the intervention in: age, swimming velocity, training volume and FINA-points. In total 15 participants completed the study, meaning that three participants were excluded from the result, two of these from UST and one from RST. The participants were excluded due to inability to attend at least 8 training sessions or inability to attend post-testing. Inability to attend training or testing sessions was accounted to respiratory sickness.

Large variations in swim bench power output were detected for intrapersonal shoulder flexions at set levels. Coefficient of variation (CV%) was calculated for intrapersonal shoulder flexions at set speed settings for power and work data, respectively. CV% for power data was considerably high and consequently excluded from the results (figure 2).

![Figure 3 - Coefficient of variation [%] at set speed setting measured as power [W] & work [Nm]](image-url)
No significant within group difference were noted between pre- and post-testing in neither RST nor UST (table 2). F-v relationships were well fitted by linear regression at pre-testing ($r^2 = 0.993 \pm 0.00$, range = 0.984-0.998, $n = 18$) and at post-testing ($r^2 = 0.992 \pm 0.00$, range = 0.977-0.998, $n = 15$).

Table 2 – Performance variables and characteristics at pre- and post-test for RST and UST groups.

<table>
<thead>
<tr>
<th></th>
<th>RST ($n = 8$)</th>
<th>UST ($n = 7$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25m swim time [s]</td>
<td>12.83 ± 0.57</td>
<td>12.43 ± 0.78</td>
</tr>
<tr>
<td>Swim velocity [m·s$^{-1}$]</td>
<td>1.94 ± 0.08</td>
<td>2.01 ± 0.12</td>
</tr>
<tr>
<td>Maximal Swim Power [W]</td>
<td>88.5 ± 21.7</td>
<td>107.7 ± 28.7§</td>
</tr>
<tr>
<td>Maximal Strength [Nm]</td>
<td>318.8 ± 76.9</td>
<td>353 ± 61.0◊</td>
</tr>
<tr>
<td>Explosive Strength [Nm]</td>
<td>175 ± 57.2</td>
<td>207.1 ± 53.4§</td>
</tr>
<tr>
<td>$F_0$ [N]</td>
<td>180 ± 35.3</td>
<td>220.9 ± 48.4</td>
</tr>
<tr>
<td>$v_0$ [m·s$^{-1}$]</td>
<td>1.85 ± 0.10</td>
<td>1.86 ± 0.13</td>
</tr>
<tr>
<td>$S_{Fv}$</td>
<td>-96.7 ± 15.2</td>
<td>-117.6 ± 20.8</td>
</tr>
</tbody>
</table>

Values are presented as mean ± standard deviation. Abbreviations: $n$ = sample size; m = meter; s = second; m·s$^{-1}$ = meters per second; W = Watts; Nm = Newton-meters; $F_0$ = maximal theoretical force; $v_0$ = maximal theoretical velocity; $S_{Fv}$ = slope of linear force-velocity relationship; § = statistical trend ($p < 0.10$); ◊ = 6 subjects tested.
Mean swimming velocity at post-testing was $1.98 \pm 0.11 \text{ m} \cdot \text{s}^{-1}$ with a range of $1.85$–$2.15 \text{ m} \cdot \text{s}^{-1}$. Strong correlations were found between swim velocity and dry-land maximal strength, dry-land explosive strength and maximal swim power (see figure 4, 5 & 6.)

**Figure 4** – Relationship between 25m swimming velocity and dry-land maximal strength

**Figure 5** – Relationship between $\Delta$% 25m swimming velocity and $\Delta$% dry-land maximal strength

Abbreviation: $\Delta$% = delta % = change %
Figure 6 – Relationship between 25m swimming velocity and dry-land explosive strength

Figure 7 – Relationship between Δ % 25m swimming velocity and Δ % dry-land explosive strength

Abbreviation: Δ % = delta % = change %
Figure 8 – Relationship between 25m swimming velocity and maximal swim power

Figure 9 – Relationship between ∆% 25m swimming velocity and ∆% maximal swim power

Abbreviation: ∆% = delta % = change %
Out of the 15 studied subjects, eight participants displayed increased, two no change and five decreased swimming velocity. The eight subjects, including four from RST and four from UST that demonstrated improved performance were analyzed separately to ascertain which characteristics increased swimming velocity could be attributed to.

Table 3 – Performance variables and characteristics for pre- and post-test for improved subjects

<table>
<thead>
<tr>
<th>Improved Subjects (n = 8)</th>
<th>Week 0</th>
<th>Week 7</th>
<th>%Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>25m swim time [s]</td>
<td>12.85 ± 0.77</td>
<td>12.61 ± 0.74***</td>
<td>1.88 ± 0.62</td>
</tr>
<tr>
<td>Swim velocity [m·s⁻¹]</td>
<td>1.94 ± 0.11</td>
<td>1.98 ± 0.11***</td>
<td>1.88 ± 0.62</td>
</tr>
<tr>
<td>Maximal Swim Power [W]</td>
<td>90.75 ± 25.24</td>
<td>98.12 ± 28.57**</td>
<td>8.12 ± 6.09</td>
</tr>
<tr>
<td>Maximal Strength [Nm]</td>
<td>339 ± 59.6</td>
<td>339.2 ± 51.2</td>
<td>0.08 ± 6.47</td>
</tr>
<tr>
<td>Explosive Strength [Nm]</td>
<td>188.5 ± 46.6</td>
<td>197.1 ± 38.3</td>
<td>4.54 ± 9.40</td>
</tr>
<tr>
<td>$F_0$ [N]</td>
<td>189.1 ± 42.0</td>
<td>198.5 ± 45.8*</td>
<td>4.98 ± 5.5</td>
</tr>
<tr>
<td>$v_0$ [m·s⁻¹]</td>
<td>1.82 ± 0.16</td>
<td>1.86 ± 0.14§</td>
<td>2.14 ± 2.98</td>
</tr>
<tr>
<td>$S_{Fv}$</td>
<td>-103 ± 21.7</td>
<td>-105.55 ± 20.1</td>
<td>-2.12 ± 7.67</td>
</tr>
</tbody>
</table>

Values are presented as mean ± standard deviation. Abbreviations: $n$ = sample size; m = meter; s = second; m·s⁻¹ = meters per second; W = Watts; Nm = Newton-meters; $F_0$ = maximal theoretical force; $v_0$ = maximal theoretical velocity; $S_{Fv}$ = slope of linear force-velocity relationship; * = significant at $p < 0.05$; ** = significant at $p < 0.01$; *** significant at $p < 0.001$. 
5 Discussion

5.1 Training Intervention

The 6-week intervention period did not evoke any significant within group difference in the examined parameters, indicating that neither training regimes were effective in enhancing swimming performance. Although some participants, from both groups, displayed substantial improvements in swimming velocity, the magnitude of these improvements were not large enough to be statistically significant for the whole group. The interpersonal variation in adaptation to the applied training regime can possibly be explained by differences in complementary training performed throughout the training intervention. Even though $RST$ and $UST$ were matched for total training volume throughout the intervention, variations in distribution of intensity could have played a crucial role in the overall training response. Considering that swimming is largely influenced by swimming technique, variations in technique training throughout the intervention could also have impacted the individual training response. Dry-land strength training throughout the training intervention was neither standardized nor controlled which could provide additional explanation to the noted variations in training response. Standardization of the complementary training was not possible because the participants were recruited from various swim clubs and therefore followed different training regimes. Nevertheless, for the purpose of this study it would have been desirable to standardize complementary training with regard to training volume, intensity distribution, technique training and dry-land strength training.

The duration of the intervention can be questioned, as whether or not it was long enough to elicit significant improvements in already well-training national level swimmers. Considering that in total eight subjects displayed improved performance during the training period indicates that the duration of the interventions was sufficiently long. Girold et al. (2006) found significant improvements following only a three weeks resisted sprint-training intervention in adolescent swimmers. However, the performance level of the examined subjects in that study was substantially lower, allowing larger improvement in shorter time. The lack of significant improvement in the present study could also partially be explained by the small sample size. However, the number of competitive swimmers at this level is scarce, limiting the possibility of studying these subjects.
5.2 Dry-land Strength & Power

The CV% for swim bench power data was identified to be high, and substantially higher than for work data. The power output attained was therefore not considered to be reliable and consequently excluded from the results. Although previous studies examining correlations between swim bench power output and swimming velocity have not presented CV% for intrapersonal shoulder flexions (Sharp, Troup & Costill 1982; Johnson, Sharp & Hedrick 1993) values above 10 cannot be considered reliable.

Figure 1 displays decreased CV% in relation to increased speed setting. A reasonable explanation to this finding would be that the drop-off throughout three shoulder flexions is higher at high resistive settings compared to low. Speed setting 1 provides the most resistance and consequently takes most time to perform. Longer time under tension combined with high resistive load could evoke larger drop of than observed at faster speed settings. A larger drop-off between the first and third shoulder flexion could be a feasible explanation to the larger CV% noted at speed setting 1 compared to speed setting 9.

It can also be noted that the CV% was considerably lower for work data compared to power data. This could possibly be accounted to a malfunctioning time measuring component in the used swim bench. Eventual variations in the time measuring would affect the velocity variable and thereby also affect power data attained. However, no further investigations were performed on the used swim bench, so it is not possible to ascertain why these large variations were noted.

The biokinetic characteristic of a swim bench is desirable in terms of emulating the stroke of freestyle and butterfly swimming by allowing acceleration throughout the motion. Although Roberts et al. (1991) showed that biokinetic swim bench training does not improve swimming performance, it can be desirable to occasionally perform biokinetic swim bench training to practice the acceleration of the arm stroke. However, the advantages of measuring dry-land power and dynamic strength in biokinetic device compared to an isokinetic device can be questioned. To date, no studies have examined if biokinetic swim benches correlate stronger with swimming velocity than corresponding isokinetic devices. Considering that biokinetic devices allow higher velocities in relation to lager applications of force, subjects with ability to produce large amounts of force will generate exponentially higher power values compared
to weaker participants. Interpersonal comparisons would therefore be misleading. By measuring power in an isokinetic swim bench where the velocity is constant throughout the motion regardless of the force applied would allow for better interpersonal comparisons.

5.3 Predictors of Swimming Velocity

$MxS$, $ExS$ and $P_{max}$ were all found to correlate strongly with swimming velocity. $ExS$ was found to correlate stronger with swimming velocity than $MxS$, indicating the importance of not only being able to generate force in swim-specific motions, but also in swim-specific velocities. Rudolph et al. 2004 (s.111) suggested that swimmers should aim at generating at least 60% of their maximal swim bench strength as explosive swim bench strength.

The correlation between swimming velocity and $ExS$ ($r = 0.82$) presented in this study was lower than earlier observed (Sharp, Troup & Costill 1982; Johnson, Sharp & Hedrick 1993). However, in these studies power output was measured making the comparison not fully valid. An advantage of measuring maximal work is that the length of the swimmer’s arms is incorporated. Longer arms allow for longer distance to produce force and consequently produce higher work values. This phenomenon can also be observed in swimming where longer arms allow for more surface area to create propulsive force and therefore being a predisposition of swimming fast (Toussaint & Beek 1992).

Another explanation to the stronger correlation between swimming velocity and dry-land power found by Sharp, Troup & Costill (1982) was that the swimmers in that study had substantially larger range in swimming velocity (1.40-2.11 m·s$^{-1}$) and dry-land power (36-490 W). However, as the range of examined values is narrowed the correlation coefficient approaches zero (Basset & Howlet 2000). With regard to the narrow range of swimming velocity (1.85–2.15 m·s$^{-1}$) found in the present study, the correlation between $ExS$ and swimming velocity ($r = 0.82$) can be viewed as noticeably high.

Based on gathered data during US Swimming Nationals 1982, Sharp (1986) compiled an article regarding muscle strength and power related to competitive swimming. It was concluded that power output could be used as a robust predictor of swimming velocity within a heterogeneous group. However, when examining elite swimmers with similar performance levels, power output could not be used as predictor of performance. It was suggested that
improvements above a certain level of power did not elicit increased swimming velocity. Elite swimmers were recommended to aim at improving technical aspects such as proper application of propulsive force and reducing active drag. These findings are not in line with the findings in the present study, indicating that high correlations can be found between swimming velocity and dry-land explosive strength even within a homogenous group of elite swimmers.

5.3 Force-velocity Profiling

Swim power assessment using isotonic loads has previously been described as a robust way of measuring $P_{\text{max}}$ (Domínguez-Castells, Izquierdo & Arellano 2013; Kojima et al. 2018). In these studies, set distance of 12.5 and 10m were used respectively for data gathering. Increased load for each trial implies extended duration of measurement throughout the test, which could potentially produce misleading results. Although raw data can be clipped (Cross et al. 2017), the difficulty of making correct assessment remains. Gathering of force, velocity and power data was therefore in this study performed by manually initiating and terminating measurements to ensure that the gathering was made within three stroke cycles. Although this at first glance can appear questionable, well-fitted $F\cdot v$ regression lines suggest a near perfect linear relationship in all tests.

In order to attain well-fitted regression lines it is of utmost importance that measurements are performed with identical conditions. During pilot testing it was noted that some swimmers tended to perform three to four under-water kicks. When the test proceeded to heavier loads (>8kg) the swimmers instinctively reduced the amount of under-water kicks and in some occasions started swimming immediately following push-off. This resulted in overestimated velocities at high loads since measurements were initiated when the swimmers still maintained high velocity from the push-off phase. The overestimated velocity at high loads produced less fitted regression lines. Following pilot testing the subjects were instructed thoroughly to perform two under-water kicks during each trail.
5.3 Interpretation of F-v Profiling and Dry-land Strength

In table 3, the eight subjects that displayed increased swimming velocity were analyzed separately in order to investigate which underlying mechanism caused the improvement. This analysis cannot be used to ascertain what type of training that caused the improvement, but merely as insight in which characteristics induced the improved swimming velocity. These subjects increased their swimming velocity on average with 1.88 % whereas \( P_{\text{max}} \) increased with 8.12 %. These findings are in line with Toussaint & Truijens (2006) who suggested that 7 % increase in \( P_{\text{max}} \) would evoke 2.3 % increase in swimming velocity. In the present study, the increased \( P_{\text{max}} \) could be traced back to a significant increase in \( F_0 \) and a trend in increased \( v_0 \). The slope of the F-v curve remained unchanged indicating no modifications to more force- or velocity-dominant profiles. No significant changes were noted in neither \( M_{xS} \) nor \( E_{xS} \) suggesting that power input did not increase, the increased \( P_{\text{max}} \) is therefore believed to have been achieved though improved swimming technique, more specifically improved propelling efficiency.

In figure 5, 7 & 9 \( \Delta \% \) correlations are presented to determine eventual casual relationships. It can be noted that \( \Delta \% \) correlations between swimming velocity and \( M_{xS} \) and \( E_{xS} \) respectively, are very weak and not significant. In practice this indicates that improvements in swimming velocity often occur without increments \( M_{xS} \) or \( E_{xS} \). The same applies the other way around, where improved \( M_{xS} \) and \( E_{xS} \) does not necessarily result in improved swimming velocity. On the other hand, \( \Delta \% \) \( P_{\text{max}} \) correlated stronger with \( \Delta \% \) swimming velocity \( (r = 0.41) \), although this correlation was not significant, it is considered relatively strong for a correlation of change between two variables. This indicates that change in \( P_{\text{max}} \), in some cases results in change in swimming velocity. If an increased \( P_{\text{max}} \) is accompanied with increased \( M_{xS} \) or \( E_{xS} \) the increased \( P_{\text{max}} \) can be attributed to increased power input. In the event that \( P_{\text{max}} \) increases but swimming velocity remains unchanged it can be interpreted as either increased active drag or decreased propelling efficiency, or a combination of both. Generally, gains in body weight; especially muscle tissue elicit increased \( F_0 \) and \( P_{\text{max}} \). However, gains in muscle tissue often coincide with decreased buoyancy thorough increased body density. Increased body density is often accompanied with increased active drag and does therefore not increase net swimming velocity (Nygren-Bonnier et al. 2007). On the other hand, if swimming velocity increases without increased \( P_{\text{max}} \) it can be attributed to either reduced active drag or increased propelling efficiency, or a combination of both.
5.4 Conclusion

Resisted sprint training in swimming using $L_{10}$ did in the present study not elicit any improvements in maximal swimming velocity or examined performance characteristics. It does not appear as resisted sprint training is a superior method of improving swimming velocity compared to unrestricted sprint training. However, resisted sprint training can be used effectively as a form of variation to unrestricted sprint training in swimming, considering that the two training methods did not elicit different adaptations in any of the examined variable. Lighter loads as $L_{10}$ can be recommended when preforming resisted sprint training. Heavier loads as $50\%$ of $F_0$ have been suggested to have detrimental effect on swimming technique and should consequently be avoided. Individualized loads can be generated accurately using the 1080 Sprint, whereas sponges and parachutes can be used as resistance devices at more casual training occasions. 1080 Sprint can be used effectively to attain force, velocity and power data during resisted swimming, as well as to perform in-water $F$-$v$ profiling. Maximal swimming velocity was found to be closely related to $MxS$, $ExS$ and $P_{max}$ indicating the importance of these characteristics. $P_{max}$ was not only observed to correlate the strongest with maximal swimming velocity but was also causally related, strengthening the argument that power assessments performed in water serve as the best predictors of swimming velocity due to the incorporation of stroke mechanics. Nevertheless, dry-land strength assessments performed in swim benches should not be neglected as they provide valuable insight regarding a swimmer’s general ability to produce maximal- and explosive strength.
References


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Svenska Simförbundet (2012-22-22) FINA poäng. 


Toussaint, H. M. (1990) Differences in propelling efficiency between competitive and triathlon swimmers, Medicine of Science and Sports Exercise, 22(3), ss. 409-415


Appendix 1: Informed Consent

1. Studiens titel

Resisted Sprint Training in Swimming – An Experimental Study on Swedish Elite Swimmers

2. Bakgrund

En mängd studier har påvisat hög korrelation mellan anaerob effektutveckling (power) på land och prestationsförmåga på 25m simning. Samtidigt är det väl känt att styrketräning som bedrivs på land med syfte att öka effektutvecklingen generellt sett har låg transfer, dvs. att det inte resulterar i någon prestationsförbättring i simning. Förklaringen tros vara att simning är en väldigt tekniskt krävande idrott och att den styrketräning som bedrivs med syfte att förbättra simprestationen behöver vara simspecifik i form av rörelsemönster och hastighet.

Majoriteten av de tidigare studierna som undersökt effekten av belastad sprintträning i simning har använt sig av elastiska slangar. Problematiken med elastiska slangar är att belastningen inte sker isotoniskt, utan snabbt ökar vilket har stor påverkan på simmarens hastighet och därmed även tekniken. Detta tros vara den huvudsakliga orsaken till att träningsinterventionerna inte resulterat i några förbättringar av simprestationen.

1080 Sprint är en relativt ny apparatur som tidigare använts på svenska landslagssimmare för att mäta effektutveckling i vattnet. En fördel med 1080 Sprint är att individuella kraft-hastighetskurvor kan skapas för varje simmare som därefter kan användas som utgångspunkt för den belastade sprintträningen. 1080 Sprint kan också ställas in så att den belastar isotoniskt, dvs. med konstant belastning. Små belastningar som påverkar simmarens obelastade simhastighet med -10 % förväntas ha liten påverkan på simtekniken och därför har potential till större transfer än det som tidigare studier påvisat.
3. Syfte

Syftet med den här studien är att undersöka effekten av sex veckors belastad sprintträning i simning på simhastigheten över 25m frisim med maximal intensitet.

4. Metod

Interventionen kommer att bestå utav sex veckors sprintträning i simning. Sprintträningen kommer att bedras två gånger i veckan i form av 8x15m med maximal intensitet, med starttid av 2min. Deltagarna kommer att delas upp i två grupper; en grupp som bedriver belastad sprintträning med en belastning som motsvarar en hastighetsförändring av -10 %, cirka (1-2kg). Samt en grupp som bedriver obelastad sprintträning. För- och eftertester kommer att genomföras en vecka innan och en vecka efter interventionsperioden. Dessa tester kommer att bestå utav 25m frisim med maximal intensitet, effektmätning i biokinetisk simbänk (Fahnemann, Tyskland) samt effektmätning i vattnet med 1080 Sprint (1080 Motion AB, Lidingö, Sverige).

<table>
<thead>
<tr>
<th>Upplägg</th>
<th>Vecka</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tester</td>
<td>6</td>
</tr>
<tr>
<td>Träningsintervention</td>
<td>7-12</td>
</tr>
<tr>
<td>Tester</td>
<td>13</td>
</tr>
<tr>
<td>Total tid i veckor</td>
<td>8</td>
</tr>
</tbody>
</table>

5. Risker

Vid belastad simning och användning av 1080 Sprint finns det risk för att försökningspersonen fastnar i snöret som används för att skapa motstånd. För att minimera risken för detta kommer en testledare alltid att manövrera 1080 Sprint. Ifall att någon skulle fastna kan belastningen på snöret avbrytas via kontrollpanelen. Dessutom finns en stop-knapp tillgänglig för att omedelbart avbryta belastningen på snöret.

6. Fördelar

Deltagaren kommer vid önskan ha möjlighet att ta del av alla sina resultat. Data gällande effektutveckling både på land och i vattnet kommer att finnas tillgänglig. Individuella krafthasighetskurvor kommer att skapas utifrån effektmätningar i vattnet. Under den pågående studien kommer deltagarna två gånger i veckan att ha möjlighet att bedriva högintensiv sprintträning med syftet att förbättra prestation sförmågan på 25m frisim.

7. Hantering av data

Personuppgifter och insamlade data kommer att hanteras i enlighet med gällande dataskyddslagstiftning.

8. Försäkring

Som deltagare kommer du vara försäkrad via Gymnastik & idrottshögskolan.

9. Frivillighet

Deltagande i studien är helt frivilligt och deltagaren kan närsomhelst avbryta sitt deltagande i studien utan att ange något skäl.
Jag har skriftligen och muntligen informerats om studien. Jag har förstått studiens syfte och genomförande och samtycker till att delta.

Jag är medveten om att mitt deltagande är helt frivilligt och att jag närsomhelst kan avbryta mitt deltagande i studien utan att ange något skäl.

Samtycke till att delta i studien

Resisted Sprint Training in Swimming – An Experimental Study on Swedish Elite Swimmers

Underskrift

Namnförtydligande

Ort och Datum
Appendix 2: Test Protocol

6:00-6:10 10min standardiserad uppvärmning på land

6:10-6:25 Power-test i biokinetisk simbänk (på land)

- Power-mätning [Watt] nivå: 1, 3, 5, 7, 9
- Arbete [Nm] nivå: 1 & 9
- 3 drag per belastning
- 2min vila per nivå
- VIKTIGT: varje drag måste göras med maximal intensitet

6:30-6:45 1000m standardiserad uppvärmning i vattnet (insim)

6:45-6:55 Ombyte till tävlingsbaddräkt

6:55-7:05 2x25m frisim max på tid

- 75m avsim efter 1:a och 2:a 25m
- Snabbast noterade tid på 25m kommer att användas som mått av prestasjon
- Starttid 3min mellan 1:a och 2:a 25m

7:10-7:30 Power-test med 1080 Sprint (i vattnet)

- 6 stebrande belastningar
- 5 cyklar (10 armtag) frisim med maximal intensitet
- 3min starttid per nivå
- VIKTIGT: endast 2 snabba kickar efter frånskjut
- VIKTIGT: varje intervall ska simmas med maximal intensitet
Appendix 3: Warm-up Protocol

På land:
20 fjärilsarm
20 fjärilsarm bak
20 bröstöppningar
20 lacourt swings
10 knäböj
20 leg swings

Insim:

600: 100frisim/50rygg
2x100: benspark
2x50: 25hårt/25löst @1:10
2x50: 15max/35löst @1:10