Load-velocity profiles as a predictor of performance level in swimming

What differentiates international elite swimmers from national elite – force capacity or efficiency?

Maria Vitazka

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Supervisor: Nikolai Baastrup Nordsborg (Copenhagen University, NEXS)
Examiner: Erik Hemmingsson
Abstract

Aim
The purposes of this study were to investigate if the load-velocity (L-V) profile parameters – force capacity and efficiency - differ between swimmers of different performance level, and to investigate if efficiency is the key performance indicator between international elite and national elite level swimmers.

Method
Fifty-four swimmers (27 female and 27 male) of either regional level, national elite or international elite level, participated in this study. The swimmers performed three 25 m semi-tethered maximum effort swims with ascending loads (1 kg, 5% and 10% of body mass). Mean velocity during three stroke cycles mid-effort was calculated and plotted as a function of the external added load. A linear regression was established, expressing the relationship between load and velocity, with the intercepts between the axes and the regression line being defined as the theoretical maximum velocity (V_0) and load (force capacity, L_0). The slope of the regression line (slope_{LV}) serves as an index of efficiency.

Results
A statistically significant difference was found between the three performance levels for all L-V profile variables for front crawl: V_0 (F [2, 51] = 7.76, p<0.001), L_0 (F [2, 51] = 5.18, p=0.009), and slope_{LV} (F [2, 51] = 3.36, p=0.043). A paired t-test revealed no difference in slope_{LV} between matched international elite and national elite level swimmers (t [9] = 1.42, p=0.188), but a near significant difference in L_0 (t [9] = 2.11, p=0.064). Both slope_{LV} and L_0 for front crawl had a strong correlation with personal best in 100 m front crawl (PB100).

Conclusion
Efficiency was not found to be the key performance indicator between matched international elite and national elite swimmers in this study, and neither was force capacity. Nevertheless, a significant difference in all front crawl L-V profile parameters was found between performance level groups, but post hoc analyses indicated no difference between adjacent performance levels neither in L_0 nor slope_{LV}. There was however a strong correlation between both slope_{LV}, and L_0, to the swimmers’ PB100. All these findings imply that efficiency and force capacity seem to be of equal importance for high performance, but swimmers use different strategies to reach the high swim velocity.
Abbreviation dictionary

BM – body mass (kg)

C_D – coefficient of drag

F_P – propulsive force

F_D – drag force (in this study used as a representation of all resistive forces)

L_0 – theoretical maximum load

LCM – long course meter, i.e. a 50 m pool

L-V – load-velocity

rL_0 – theoretical maximum load relative to body mass

rslope_{L,V} – slope of regression line of velocity measurements and load relative to body mass

SCM – short course meters, i.e. a 25 m pool

SL – stroke length

slope_{L,V} – slope of the regression line of the load-velocity measurements

SR – stroke rate

V_0 – theoretical maximum velocity

v_{max} – maximum velocity

VPM – velocity perturbation method

WA – World Aquatics, formerly known as FINA (Fédération Internationale de Natation)
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1 Introduction

For any movement to start a force needs to be applied onto a surface or environment. In sports where a distance needs to be covered in the fastest time possible, the athlete’s capacity to generate force, and ability to apply it effectively onto the environment are key determinants of performance (Morin et al., 2011a; Morin & Samozino, 2016). In aquatic movements these capacities are even more important since water is 800 times denser than air, making the relationship between forces and velocity even more complex. For a swimmer to start moving, or accelerate, hydrodynamic reaction forces, or propulsive forces ($F_p$) need to be applied by the swimmer onto the water to overcome the resistive forces (drag forces; $F_D$) that act on the swimmer in the water (Toussaint et al., 2000). A challenge with aquatic movements is that the faster a body moves through the water there is increased movement of water around the body, creating larger resistance for the body to overcome. Key parameters for performance in swimming are therefore the capacity to generate force and ability to apply it effectively in the water (Gatta et al., 2017), as well as the ability to minimize $F_D$ (Maglischo, 2003).

Athletes can have a different combination, or balance, between force and velocity capacities, and be either force dominant or velocity dominant, which means they have different mechanical effectiveness in their movements when accelerating (Morin & Samozino, 2016). This is also the case in swimming, where two swimmers might be able to reach the same maximum velocity but with different efficiency – a force dominant swimmer can reach a high velocity by generating higher $F_p$ but does so with increased $F_D$, and a velocity dominant swimmer can reach the same high velocity with less $F_p$ because of lower $F_D$ and more efficient force application (Dominguez-Castells et al., 2013).

Assessing the velocity and force capacities of swimmers can provide insights into which capacity needs to be improved upon to reach the next level of performance – increasing the force capacity (i.e. improving strength) or improving efficiency (i.e. better ability to apply force propulsively, and reducing $F_D$). Force-velocity profiling is one assessment method being used in several sports, including swimming. Few studies in swimming take performance level into account when looking at force capacity and efficiency, but a higher competitive level could mean a higher ability to transfer strength into force in the water, a higher efficiency, or a combination of the two.
1.1 Velocity determinants in swimming

A swimming performance can be broken down into several phases: the start, underwater phases (directly after the start and each turn), free-swimming phases, and turns. The start, underwater phases, and turns account for about 30% of the final race time and are as such important phases of a swimming performance (Morais et al., 2019). The free-swimming phase has a larger impact on performance as it makes up a larger portion of the race. And as such the main objective in competitive swimming is to reach the highest swimming velocity during the free-swimming phase and maintain it for as long as possible.

Free-swimming velocity depends on several factors but can be determined by the stroke rate (SR) times the distance moved through the water with each stroke cycle (stroke length, SL) (Craig et al., 1985). The combination of the swimmer’s SR and SL determines the swimming velocity (Peterson Silveira et al., 2019), and these variables are also linked to the forces. Higher SR is correlated to higher $F_P$ (Koga et al. 2022), but when the higher SR comes at a cost of shorter SL there is a decrease in $F_P$ and hence decreased velocity (Keskinen et al., 1989). Stroke rate and stroke length are variables that are well-researched and most used by coaches as metrics to follow up and improve upon. Forces, however, both propulsive and resistive, are still variables that need more research and easier testing methods.

1.1.1 Propulsive force capacity

To reach high free-swimming velocity swimmers need the ability to generate high muscle force and the technical skills to apply that force into movements in the water, i.e. the ability to transfer muscle force into hydrodynamic forces (Maglisco, 2003). Correlations between general on-land strength capacity and swim performance have been shown, especially in movements very similar to the swimming motions (Morouco et al., 2011; Crowley et al., 2017). Measuring force capacity on land only indicates the ability to generate muscle force however and does not take into account the ability to convert this force into movements in the water.

It is rather complex to measure propulsive forces generated by the swimmer, as well as the resistive forces acting on a swimmer due to the unsteady flow around the swimmer’s body (Samson et al., 2018). Santos et al. (2021) summarized the direct assessment methods of measuring swimmers’ propulsive force capacity, with 29 of 35 articles using tethered force measurements and six studies using a differential pressure method. Tethered force
measurements are considered the golden standard for measuring force in swimming (Morouco et al., 2011 and 2014). During the measurement the swimmer is attached to a load cell by a non-elastic wire, and the force generated while swimming in a fixed position is measured. This is an efficient way to assess how much muscle force is generated during swimming motions in the water, but it does not take into account efficiency of force application. In some sports, and especially in swimming, not all force generated will be propulsive, as hand and arm movements executed in the transverse plane or vertically will reduce the propulsive force application (Van der Kruk et al., 2018). Furthermore, the tethered measurements are at zero velocity, which creates larger resistance against the hands and feet which in turn means the swimmer will adjust the swimming technique slightly compared to free-swimming conditions (Samson et al., 2019). Also, when the swimming movement is performed without forward displacement, only assumptions can be made regarding how the force measured corresponds to the velocity the swimmer can obtain when swimming in free conditions. There are a few more limitations with tethered measurements such as the water flow around the swimmer does not represent the free-swimming conditions (Barbosa et al., 2010), or the absence of $F_D$ (Amaro et al., 2017; dos Santos et al., 2013).

Using the tethered measurement method in a flume creates a state more similar to free-swimming conditions even if the swimmer is stationary, and it has been shown that as the water flow speed increases the correlation between force generated and speed decreases (Vorontsov et al., 2006). This indicates that the force at zero velocity (stationary) correlates better to muscle strength, and as velocity increases the ability to apply force in the water becomes more important. This means that it is not necessarily the swimmer with the highest force capacity that can achieve the highest swim velocity, since the ability to efficiently apply the force in the water is also an important factor.

A couple of more direct force assessment methods are worth mentioning to show the complexity of measuring in free-swimming conditions. Koga et al. (2022), Tsunokawa et al. (2019), and Schnitzler et al. (2011) have used different pressure sensors to estimate forces of the hands during free-swimming. There are some limitations with these methods as well, such as a change in technique, increased $F_D$ due to wires between sensors, limited movement due to sensors being glued onto gloves, and an increased frontal surface area. The measuring active drag (MAD) system requires the swimmer to push against fixed pads when swimming to get estimates of $F_P$ and $F_D$. Measurements with the MAD-system have
found that the force applied by the swimmer is in direct relationship with swim velocity and SR, and an inverse relationship with SL (Ribeiro et al, 2013). One limitation of the MAD-system, however, is the fact that the pads that the swimmer push against are at a fixed distance from each other, i.e., SL is fixed, and the swimmer needs to adjust their normal SL and SR strategy.

In recent years semi-tethered force measurements, such as load-velocity testing with a robotic resistance device such as 1080 Sprint (1080 Motion AB, Lidingö Sweden), has been used as the testing more closely resemble free-swimming conditions. These measurements allow for assessing swim specific strength during forward motion with added external load, and it is an easier way to assess swimmer’s force capacity and velocity capacity simultaneously with using only one device.

1.1.2 Efficiency

In sports mechanical efficiency describes the athlete’s ability to transfer energy consumed into performing external work. Higher efficiency means the athlete moves with using less of the energy consumed toward the external work. In swimming it is difficult to measure both external work (power or force output), and energy consumed (maximum oxygen uptake) in free-swimming conditions. In addition, due to higher resistive forces in swimming than in land-based sports, reducing $F_D$ is an important aspect in swimming. The term efficiency in swimming therefore often refers more to the technical, or propelling efficiency of the swimmer. Propelling efficiency in swimming is the amount of energy used to overcome $F_D$ and propel the body forward, as a percentage of the total energy required to overcome drag, move the limbs, and energy wasted to the water (Barbosa, 2018). Or simply put, swimming efficiency is achieving a higher velocity with less energy being wasted to overcome resistive forces acting on the body by the water (lower $F_D$), and as such lower $F_P$ is required to reach the higher velocity.

At maximum swimming velocity $F_P$ and $F_D$ are in balance (Toussaint et al., 1992, Gatta et al., 2016), and as stated above, to increase velocity either $F_P$ will have to increase or $F_D$ decrease, or a combination if the two. The “super suits” that swimmers could compete in during 2007-2009 are an example of $F_D$ being decreased artificially (i.e., not through improved technical efficiency), thus allowing for higher swimming velocities with the same max $F_P$ as without “super suits.” Achieving an efficient technique is a key aspect for fast swimming.
performance. The ability to minimize $F_D$ is perhaps even more important than maximizing $F_P$ because $F_D$ increases exponentially as swimming velocity increases:

$$F_D = \frac{1}{2} \rho A C_D v^2$$

This drag force equation consists of $\rho$ which is the mass density of water, $A$ is the frontal surface area of the swimmer, $C_D$ is the coefficient of drag, and $v$ is velocity. Reducing frontal surface area by having a better body position in the water will lower $F_D$. The coefficient of drag varies depending on the swimmer’s size and position, as well as flow speed and direction. A lower $C_D$ means reduced drag, i.e., higher technical efficiency.

In research studies on $F_D$ both passive and active drag are considered, with passive drag being $F_D$ acting on the body when it is being towed in a hydrodynamic stable position (Havriluk, R. 2007, Gatta et al., 2015). Active $F_D$ acts on the swimmer while swimming, which is difficult to measure, but some research groups have attempted to assess it (di Prampero et al. 1974, Kolmogorov & Duplischeva 1992, Zamparo et al., 2009). The different methods are questioned as they all involve assumptions and are indirect measurements where active drag is calculated. Di Prampero et al. (1974) compared the oxygen consumption between assisted and resisted conditions and mathematically calculated active drag. Ribiero et al. (2013) estimated active drag from measuring force applied with the MAD-system, and Kolmogorov and Duplischeva (1992) used the velocity perturbation method (VPM) where maximal efforts with and without an added external load are used to estimate active drag. VPM is preferred as it best mimics the free-swimming condition. With newer technology like the 1080 Sprint, VPM estimates of active drag have been found reliable if the added loads are not too light or heavy as to not violate the assumption that the swimmer has a similar power output with and without added load (Gonjo & Olstad, 2022). These types of measurements provide insights into the swimmer’s ability to reduce $F_D$ from the linear relationship between swimming velocity and force capacity, with the slope of the linear relationship being an indicator of swimming efficiency.

### 1.2 Load Velocity Profiles

This linear relationship between force and velocity can be used to understand how these variables interact, and how they contribute to performance. There are many different methods used to obtain the force and velocity data, depending on the sport, but most common is measuring velocity with timing gates, laser, radar or video analysis, and force with force plates or by calculations from repeated measures of for example jump height with increasing
added loads (Morin & Samozino, 2016). In recent years motorized sprint resistance devices have gained popularity, and Rakovic et al. (2022) showed that the 1080 Sprint device is valid and reliable for sprint running performance monitoring, and Olstad et al. (2020) have demonstrated the same for sprint front crawl swimming. When using the semi-tethered approach with the 1080 Sprint device different external resistive loads are used, which then provides a load-velocity (L-V) profile as an alternative to force-velocity profiles.

Parameters that the L-V profile provides are an athlete’s theoretical maximum velocity ($V_0$) and theoretical maximum load capacity ($L_0$). The slope of the linear regression of this load-velocity relationship ($\text{slope}_{LV}$) serves as an index of efficiency that indicates the athlete’s ability to utilize muscular force capacity (ability to apply force) and ability to minimize $F_D$. This provides insights into whether the athlete is force dominant or velocity dominant, and hence information on which capacity needs to be improved upon for higher performance level.

1.2.1 In other sports

The uses for L-V profiling in sports are many, especially in those sports that require jumping, sprinting and a high ability to accelerate. In research the use ranges from assessing different sprint training regimens in adolescent soccer players (Derakhi et al., 2021) and in professional rugby players (Lahti et al., 2020), to looking at key determinants in performance for international elite sprint runners (Rabita et al., 2015), to the role of technical ability of force application in recreational level team sport players (Morin et al., 2011a).

Morin et al. (2011) found a significant correlation between the technical ability to apply force in the correct orientation and the 100 m sprint performance (2011a). They also found that the capacity to produce force decrease with fatigue, and that the ability to apply it effectively decreases even more (Morin et al., 2011b). Efficient force application onto the surface or environment has been shown to account for the difference in performance between international elite level and sub-elite level sprint runners (Rabita et al., 2015). This efficiency would be an important factor to look at in swimming as the force is applied into a fluid environment. $\text{slope}_{LV}$ could therefore be a key indicator of performance level.

Anthropometric differences influence force capacity of an individual, with a larger body mass being able to generate more force (Kjendlie & Stallman, 2011). This means there are differences between male and female L-V profiles, since men typically have larger body mass
and can generate more force than women. Mirkov et al. (2020) found that for any level of training in sprint runners, men displayed higher force capacity and higher velocity capacity than women. Galantine et al. (2023) on the other hand also studied sprint runners and found that there were no gender differences in $L_0$ if normalized to body mass, but there was a gender difference when normalized for other anthropometric parameters important to sprint running. $\text{Slope}_{LV}$ was not significantly different between genders when maximum force was in absolute values but was found significantly different when maximum force was relative to body mass (Galantine et al., 2023). In swimming, a larger body mass is an advantage in terms of a higher $L_0$ but a disadvantage in terms of a larger frontal surface area in the direction of the movement in the water, hence larger $F_D$. Male swimmers with larger body mass might be able to generate more force, but at the same time experience higher drag. Female swimmers might have a smaller body mass and possibly higher percentage body fat that increases bouyancy, which means female swimmers could have a higher index of efficiency because they have less drag due to smaller frontal surface area and a better body position in the water.

### 1.2.2 In swimming

The semi-tethered measurements are as close as we can get to free-swimming conditions and measure the force capacity and velocity capacity simultaneously. The L-V profiles that are generated from these measurements have shown a highly linear relationship between swimming velocity and external loads (Gonjo et al., 2020a, Olstad et al., 2020). The L-V profiles can be used to assess the swimming-specific strength and velocity capabilities for front crawl sprint swimming (Gonjo et al. 2021) and butterfly sprint swimming (Gonjo et al. 2020). Gonjo and Olstad (2022) also showed that three loads were enough to establish a load-velocity profile, as too many trials ascending to too heavy loads would lead to failure to perform the tests at maximal effort due to fatigue.

In swimming L-V profiling $V_0$ theoretically corresponds to the maximum swimming velocity the swimmer can achieve during free-swimming conditions at zero load, which means swimmers of higher performance level should have higher $V_0$. $L_0$ theoretically corresponds to the maximum force the swimmer can generate during a tethered measurement at zero velocity (Cross et al., 2017). The steepness of $\text{Slope}_{LV}$ indicates both the ability to apply force efficiently and the ability to reduce drag forces, possibly making $\text{Slope}_{LV}$ the key performance indicator that differentiates the international elite from the national elite level swimmers.
1.3 Aim of the study

Most load-velocity profiling research to date has been performed on limited cohort of swimmers of mostly national elite level male swimmers. The aim of this study was to investigate if the L-V profile parameters differ between swimmers at different performance levels, regardless of gender. With efficiency being more linked to the swimmer’s technical ability rather than the swimmer’s anthropometry or gender, another aim was to examine more closely if slope_LV is the key performance indicator that separates international elite from national elite swimmers. Furthermore, this study also wanted to investigate the relationship between an individual’s L-V profile parameters and their best race performance.

This study’s hypotheses were therefore: 1) L-V profile parameters are different between swimmers of different performance level, 2) international elite swimmers have a steeper slope_LV than national elite swimmers (i.e., higher technical efficiency), and 3) there is a relationship between a swimmer’s L-V profile parameters and the swimmer’s best race performance.

2 Methods

2.1 Participants

Swimmers of national and international elite level were recruited from the Danish National Training Centre (NTC) and local swim teams in Copenhagen, Denmark. A total of 54 swimmers participated in the study (male n=27, female n=27). The criteria were to be healthy and injury free, and at the minimum be qualified for a Danish national championship (senior, junior or youth).

Anthropometric data such as body height (m) and body mass (kg) were collected prior to the in-water tests. The swimmers’ personal best times and corresponding best World Aquatics Points (WA points; according to World Aquatics Point Scoring), formerly known as FINA points, were recorded for front crawl and specialty stroke. Swimmers were divided into Levels based on their best WA points in the past 12 months, according to Ruiz-Navarro et al., (2023) classifications to standardize research results in swimming. The different classifications are Level 1: >875 WA points (corresponding to WA A qualification standard for international championships), Level 2: 800-874 WA points (corresponding to WA B qualifying standard for international championships), Level 3: 650-799 WA points (corresponding to lowest WA points in national championships, i.e. national elite), Level 4:
450-649 WA points (corresponding to lowest WA points at regional competitions, i.e. regional swimmers), and Level 5: <450 WA points. A summary of this study’s cohort can be seen in Table 1.

The swimmers were given verbal and written explanation of the purpose and procedures of the study prior to their participation. The subjects or a legal guardian (for swimmers under the age of 18 years) provided written informed consent to participate in the study. The protocol was evaluated by the local Danish ethics committee and procedures were found to be in accordance with national legislation (Ref F-23006844). To keep all collected personal data in accordance with GDPR regulations each subject was assigned an ID number to keep the subjects anonymous in the results of the study.

2.2 Procedures

Data collection was conducted at Bellahøj Swim Stadium an indoor LCM pool (water temperature 27 C°, air temperature 28 C°) during four separate testing sessions. All testing sessions were within an eight-day period, when all swimmers in this cross-sectional study were in the same phase of preparation 3-4 weeks prior to a major qualification competition. Swimmers started the session with their individual pre-competition warm-up of about 45 minutes (on land and in water preparations), like they would do during an actual competition. The swimmer then conducted a semi-tethered swim test of 3x25 meters maximum effort front crawl with ascending load. The swimmer was attached via a non-elastic cord to the 1080 Sprint (1080 Motion AB, Lidingö Sweden), a robotic resistance device that applied the external load while swimming, that measured both velocity and force. The non-elastic cord from the 1080 Sprint was attached to a belt (S11875BLTa, NZ Manufacturing, OH, United States) attached around the swimmer’s hip. The 1080 Sprint device was attached on top of a starting block, which elevated the origin of the cord to 0.87 m above the water surface (Figure 1). This elevation was done to minimize the possible disruption in the technique to avoid kicking the cord; any kicking of the cord would influence the data collected so this must be eliminated as much as possible. To avoid potential over- or underestimation of the velocity due to the push-off or due to fatigue at the end of the trial, three consecutive stroke cycles at the middle of the trail were used.

The ascending loads were 1 kg, 5% of body mass (BM) and 10% of BM, for both females and males, and the rest interval between each trial was 4 minutes. A protocol with ascending loads relative to the swimmer’s BM was used to make the tests more comparable between
individuals, between performance levels and between genders. To ensure reproducibility the following 1080 Sprint settings were used, as described by Olstad et al. 2020: isotonic resistance mode, gear 1, eccentric velocity 0.05 m/s, concentric velocity 14 m/s, and with load parameters (kg) described above. Data was collected with sampling frequency of 333Hz, from the 5.0 m mark to the 20.4 m mark of each 25m trial. Since the 1080 Sprint was positioned 0.87 m above the surface the measured velocity is not horizontal, and as such the following equation from Gonjo et al. (2020) was used to adjust:

\[ V_H = V \times \cos[\sin^{-1}(0.87/L_C)] \]

where 0.87 is the height above water surface, and \( L_C \) the length of the cord (m) from the device at each sampling point.

![Diagram of 1080 Sprint setup](image)

**FIGURE 1** | Illustration of 1080 Sprint set up, with \( L_C \) being the length of the cord, \( V \) the measured velocity, and \( V_H \) the adjusted horizontal velocity (Gonjo et al., 2021)

Linear regression of the velocity and load data provided \( V_0 \) as the theoretical maximal velocity at zero load, \( L_0 \) as the theoretical maximum load at zero velocity (Samozino et al., 2015), as well as the slope of the regression line calculated as \(-V_0/L_0\) (Gonjo et al, 2021). To account for differences in body size \( L_0 \) was expressed as a percentage relative to body mass \((rL_0)\), with an adjusted slope for that linear relationship \((rslope_{LV})\).

Swimmer’s best WA points in their specialty stroke were used to determine performance Level, and those swimmers that had a specialty stroke other than front crawl got to repeat the semi-tethered tests in their specialty stroke as well, with the same protocol and load as for front crawl. When a swimmer performed both front crawl and specialty stroke tests there was
a minimum of 30 minutes active recovery and rest between tests. The cohort’s distribution of specialty strokes, and descriptive statistics by Level can be found in Table 1 below.

| TABLE 1 | Descriptive statistics for each Level, and breakdown of number (n) of participants by gender and specialty stroke. Age, body mass, height and WA points are reported in mean (± standard deviation). Specialty stroke is the stroke in which the swimmer has the highest WA points. |
|----------|-------------------------|-------------------------|-------------------------|
|          | Level 2 (n=15)          | Level 3 (n=21)          | Level 4 (n=18)          |
| Gender   | 7                       | 12                      | 8                       |
|          | female                  | male                    |                          |
|          | 8                       | 9                       | 10                      |
| Age      | 21.1 (± 2.7)            | 18.0 (± 1.5)            | 16.8 (± 1.8)            |
| Body mass (kg) | 78.1 (± 9.5)       | 71.0 (± 9.7)            | 67.5 (± 9.8)            |
| Height (m) | 1.85 (± 0.09)        | 1.80 (± 0.1)            | 1.76 (± 0.1)            |
| WA points | 836 (± 22)             | 719 (± 38)              | 581 (± 44)              |
|          | 95% CI lower            | 95% CI upper            |                          |
|          | 824                     | 702                     | 559                     |
|          | 848                     | 737                     | 603                     |
| Specialty stroke | Butterfly       | 6                       | 5                       | 3                       |
|          | Backstroke              | 1                       | 3                       | 4                       |
|          | Breaststroke            | 4                       | 2                       | 4                       |
|          | Front crawl             | 4                       | 11                      | 7                       |

### 2.3 Statistical analysis

All statistical analysis was performed in Jamovi open-source statistical software (The jamovi project (2022) jamovi (Version 2.3) [Computer Software]. https://www.jamovi.org). The alpha level of significance was set to \( p < 0.05 \). A Shapiro-Wilks test was used to check for normal distribution of the data for each Level. The variables had normal distribution except \( L_0 \) for Level 3 and Level 4 (\( W=0.897 \) \( p=0.031 \) and \( W=0.873 \) \( p=0.020 \) respectively). The swimmers were placed in a Level based on their best WA points in their best event (specialty stroke and distance). Levene’s test was used to test assumption of homogeneity of variance in the Levels, and the test was not statistically significant for any of the variables indicating that the variances in the three groups were roughly equal.
To investigate the first hypothesis if the L-V profiles differ for swimmers of different performance levels, a one-way ANOVA was performed to investigate between and within group variances. For this analysis front crawl data was used as all swimmers performed front crawl L-V tests. A Tukey HSD post hoc analysis was performed to look closer at potential differences between adjacent performance levels and between Level 2 and Level 4.

To answer the second hypothesis if slope_{LV} is a key performance indicator that separates international elite (Level 2) from national elite (Level 3), a paired-samples t-test was conducted to compare the L-V profile parameters – V₀, slope_{LV}, and L₀. Swimmers from Level 2 and Level 3 were matched up according to gender, size (BM and height) and specialty stroke. A total of 10 pairs were identified and used in this analysis: 5 pairs of female swimmers and 5 pairs of male swimmers, and L-V profile data in their respective specialty stroke was used for the analysis.

To answer the third and final analysis if there is a relationship between swimmers’ front crawl L-V profile parameters and their best race performance, simple linear regressions were performed for the swimmers’ personal best in 100 m front crawl (PB100) in long course meter (LCM) and their front crawl L-V data. A simple linear regression was chosen for this analysis over Pearson’s correlation as it is of interest to investigate if slope_{LV} or L₀ can be used to predict performance level, and because PB100 is not interchangeable with the L-V variables. The L-V variables slope_{LV} and L₀, as well as the variables relative to the swimmers’ BM (rslope_{LV} and rL₀) were used in the simple linear regressions, and gender was also used as a factor.

3 Results

Figure 2 a-b illustrates an example of the front crawl L-V profiles for Level 2 swimmers, split up a) male swimmers and b) female swimmers. Table 2 provides a description of the matched paired swimmers, as the mean difference (±SD) in BM and height to demonstrate the level of agreement in body size of the matched pairs. Table 3 provides an overview of the mean values (±SD) for front crawl L-V profile parameters for the three Levels.
FIGURE 2 a-b | Visualization of front crawl L-V profiles of a) male Level 2 swimmers, and b) female Level 2 swimmers.

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Matched pairs of swimmers descriptive statistics as mean difference (± standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (m)</td>
</tr>
<tr>
<td>Female</td>
<td>0.03 (± 0.01)</td>
</tr>
<tr>
<td>Male</td>
<td>0.05 (± 0.02)</td>
</tr>
<tr>
<td>Total</td>
<td>0.04 (± 0.02)</td>
</tr>
</tbody>
</table>
3.1 Difference in L-V profile parameters by performance levels

For the first hypothesis that L-V profile parameters differ between performance levels the ANOVA tests showed a statistically significant difference between the levels in all L-V profile variables for front crawl: $V_0$ ($F[2, 51] = 7.76, p<0.001$), $L_0$ ($F[2, 51] = 5.18, p=0.009$), and $slope_{LV}$ ($F[2, 51] = 3.36, p=0.043$). Tukey HSD post hoc analysis revealed that mean $V_0$ is statistically different between Level 2 and Level 3 ($t[51] = 2.76; p=0.021$), as well as between Level 2 and Level 4 ($t[51] = 3.88; p<0.001$), but not statistically different between Level 3 and Level 4 ($t[51] = 1.32; p=0.393$). There was a statistically significant difference in mean $L_0$ and mean $slope_{LV}$ of Level 2 and Level 4 ($t[51] = 3.20; p=0.007$ and $t[51] = 2.56; p=0.035$ respectively) but not between Level 2 and Level 3 ($t[51] = 2.11; p=0.098$ and $t[51] = 1.11; p=0.513$) nor between Level 3 and Level 4 ($t[51] = 1.26; p=0.422$ and $t[51] = 1.62; p=0.247$).

3.2 SlopeLV as key performance indicator

For the second hypothesis that $slope_{LV}$ is the key performance indicator between Level 2 and Level 3 the paired t-test found no statistical significant difference in $slope_{LV}$ ($t[9] = 1.42, p=0.188$). In terms of the other L-V parameters there was a statistically significant difference in $V_0$ between Level 2 and Level 3 swimmers ($t[9] = 3.09, p=0.013$), and a near significant difference in $L_0$ ($t[9] = 2.11, p=0.064$). The paired t-test results can also be seen in Figure 3a-c and in Table 4.

<table>
<thead>
<tr>
<th>Level</th>
<th>$V_0$ (m/s)</th>
<th>$L_0$ (kg)</th>
<th>$slope_{LV}$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2</td>
<td>1.83 ± 0.12</td>
<td>18.1 ± 6.91</td>
<td>-0.113 ± 0.034</td>
<td>0.993 ± 0.007</td>
</tr>
<tr>
<td>Level 3</td>
<td>1.72 ± 0.11</td>
<td>14.6 ± 4.02</td>
<td>-0.124 ± 0.026</td>
<td>0.995 ± 0.007</td>
</tr>
<tr>
<td>Level 4</td>
<td>1.67 ± 0.13</td>
<td>12.7 ± 3.62</td>
<td>-0.140 ± 0.033</td>
<td>0.995 ± 0.005</td>
</tr>
</tbody>
</table>
FIGURE 3 a-c | Graphical representation of difference on L-V profile parameters, a) $V_0$, b) $L_0$, c) Slope$_{LV}$ in matched swimmers of Level 2 and Level 3.
3.3 Relationship between L-V parameters and PB100

For the third hypothesis that there is a relationship between the swimmer’s L-V profile parameters and the swimmer’s PB100, both $L_0$ and $\text{slope}_{LV}$ were found to have a medium to strong relationship to PB100 (Figure 4a-b). For the relationship between PB100 and $\text{slope}_{LV}$ the combination of predictors were significantly related to PB100 ($F[3, 50] = 35.2, p<0.001$, adjusted $R^2 = 0.659$). $\text{slope}_{LV}$ and $\text{rslope}_{LV}$ were found to significantly predict PB100 ($t[50] = -6.119, SE = 24.69, p<0.001$ and $t[50] = 3.024, SE = 39.35, p=0.004$ respectively), but gender not ($t[50] = -0.441, SE = 0.97, p=0.661$). Likewise the relationship between force capacity and PB100 the combination of force predictors were significantly related to PB100 ($F[3, 50] = 35.8, p<0.001$, adjusted $R^2 = 0.663$). $L_0$ was found to significantly predict PB100 ($t[50] = -4.745, SE = 0.18, p<0.001$), but $rL_0$ and gender not ($t[50] = 1.412, SE = 0.17, p=164$ and $t[50] = -0.688, SE = 0.94, p=0.495$ respectively).

![Figure 4a-b Linear relationship between PB100 and L-V parameters](image-url)
4 Discussion

The aims of this study were three-fold – first to determine if the front crawl L-V profile parameters are different for swimmers of different performance levels, second to investigate if slope_{LV} is the key performance predictor that separates international elite and national elite level swimmers, and lastly to investigate the relationship between a swimmer’s front crawl L-V profile parameters and personal best in 100 m front crawl. Results of this study show that the front crawl L-V profile parameters do differ between the performance levels, and that there is a strong relationship between the L-V parameters and the swimmer’s personal best. When comparing international elite with national elite swimmers of same gender, body size and specialty stroke the results of this study indicate that, at least for these swimmers, neither slope_{LV}, nor L_0, are predictors of performance level on their own. A high V_0 can be achieved either by high L_0, or by a steeper slope_{LV} (higher efficiency), or by a balance between the two that is beneficial to the individual swimmer.

Research on load-velocity profiles in swimming to date have been done on national elite level swimmers which corresponds to Level 3 (650-799 WA points) of this study, if the classifications of Ruiz-Navarro et al. (2022) are used. In fact, most participants in previous studies (Gonjo et al., 2020a, Gonjo et al., 2021, Olstad et al., 2020) have had a performance level lower than 700 FINA points, hence this study is the first attempt to compare groups of swimmers at different performance levels, from regional level swimmers (Level 4; 450-649 WA points), to national elite (Level 3; 650-799 WA points) to international elite (Level 2; 800-874 WA points corresponding to WA B qualifying standard for international championships).

Studies published to date on L-V profiling have also used a fixed protocol of 1, 3, 5 kg for females, and 1, 5, 9 kg for males (Olstad et al., 2020 and Gonjo & Olstad 2022). These fixed protocols have been shown appropriate for front crawl swimming by but there are some possible limitations because for some international elite female swimmers the 5 kg might be too light to get a reliable test outcome, and similarly for a male swimmer with a smaller body size 9 kg added load could be too heavy. In this study a protocol with ascending loads based on the swimmer’s BM was used instead, in order to better compare the swimmers of the three different performance levels.
4.1 Difference in L-V parameters by performance level

The main finding of the first aim of the study was a statistically significant difference in all front crawl L-V parameters ($V_0$, $L_0$, slope$_{LV}$) between the three performance levels. Since performance level was the determining factor in this analysis it is logical that mean $V_0$ for the groups were found to be significantly different. However, post hoc analysis revealed that there was no significant difference in mean $V_0$ between Level 3 and Level 4 swimmers. This could be due to the fact that the swimmers were grouped based on their best performance in LCM in the past 12 months, and many swimmers had not competed in LCM in 5-6 months and could potentially be at a higher performance level at the testing occasion. Gonjo et al. (2021) had a front crawl race simulation swim performed during the same testing session as L-V tests, and they found that $V_0$ is correlated to a swimmer’s maximum free-swimming velocity ($v_{\text{max}}$), which should estimate the performance level of the swimmer. However, as the race simulation was a 50 m front crawl swim in a short course pool (25 m, SCM) $v_{\text{max}}$ is influenced by the start, underwater swimming and turns, thus over-estimating $v_{\text{max}}$ compared to $V_0$. As all swimmers in the present study were in a preparatory phase 3-4 weeks prior to their first major long course competition of the season, i.e., close to peak performance condition, a race simulation in LCM, would have been a good estimation of current performance level.

4.1.1 $L_0$

Force capacity (mean $L_0$) was significantly different between the three performance levels. However, the post hoc analysis in this study indicated no significant difference in mean $L_0$ between Level 2 and Level 3, nor between Level 3 and Level 4 ($t\ [51] = 2.11; \ p=0.098$ and ($t\ [51] = 1.26; \ p=0.422$ respectively). It is likely that the group mean $L_0$ can be influenced by the Level-groups being mixed gender and swimmers with different specialty stroke. Differences in anthropometric variables could also have influenced the mean $L_0$ of these Levels. In sprint runners age, performance level, technique and gender were factors identified to influence the L-V profile, such that men display both higher force and velocity capacities than women at all levels (Mirkov et al. 2020). However when normalized for BM no gender differences were seen the in L-V profiles of sprint runners (Galantine et al., 2023). In swimming a strong correlation between $L_0$ and anthropometric variables like body mass, arm span and height were found for front crawl L-V profiling (Gonjo et al., 2021) but not in butterfly L-V profiling (Gonjo et al., 2020a), implying that $L_0$ is more linked to anthropometric variables in front crawl. Male swimmers, at national and international elite levels, typically have larger
body size (higher BM and height), and thus a higher force capacity than female swimmers. A larger body size is positively correlated with $F_p$ production (Kjendlie & Stallman, 2011), but a larger body size also means larger frontal surface area when moving through the water and thus increased $F_D$ (Gatta et al., 2015; Gonjo et al., 2020b). As such, having larger body size and consequently a higher force capacity requires a higher level of efficiency to overcome higher drag forces. Swimmers of the same gender and similar size should have similar force capacity, but they might not have the same efficiency, or ability to apply the force in the water (Dominguez-Castells et al., 2013, Santos et al., 2021), which also could account for the post hoc analysis findings.

### 4.1.2 Slope$_{LV}$

In terms of efficiency, there was a statistically significant difference in mean slope$_{LV}$ between the performance levels. It could be expected that a swimmer at a higher performance level would be more efficient at utilizing his or her force capacity to reach higher swim velocities. In sprint running, efficiency of force application has been shown to be a key performance variable (Morin et al., 2011a), and to be higher in international elite than national elite (Rabita et al., 2015). Similarly in swimming, Ruiz-Navarro et al. (2022) found very large correlations between the relative change in maximum force ($F_p$), average force, and performance, which they claim could be a way to quantify the ability to apply force in the water. However, the study only included regional level swimmers, which is only one of three levels in this present study. The importance of efficiency, or ability to apply force in the water, has also been shown to increase as water flow around the body increases (Vorontzov et al., 2006). The Vorontzov study was performed with tethered force measurements in a flume to mimic the free-swimming condition however, and it is questionable whether the swimmers maintain their normal swimming technique in these conditions, as tethered swimming has been shown to alter the swimmer’s technique (Samson et al., 2019). Zamparo (2006) found a difference in efficiency between male and female swimmers, but the efficiency was not compared at identical speeds making the findings inconclusive.

A swimmer’s specialty stroke could be a factor to consider in this analysis as front crawl measurements were used for these comparisons. Front crawl L-V data was used even if the swimmer was placed in a performance level based on their best WA points in another stroke than front crawl. There is no simple way to compare strokes as they differ in their movement patterns (Morouco et al., 2011). The alternating strokes, front crawl and backstroke, are
similar because they have more or less continuous propulsion from one arm always providing $F_P$. In butterfly and breaststroke there is no propulsion during the simultaneous recovery of the arms above the water. Butterfly and breaststroke require higher $F_P$ to overcome the higher $F_D$ due to the zero-propulsion phase and more vertical movements. Efficiency could be of greater importance in butterfly and breaststroke compared to front crawl and backstroke (Gonjo et al., 2020a; Gonjo et al., 2021), but further research on the differences in L-V profiles and the different demands of the swim strokes is needed as the studies to date are done on limited groups of male swimmers of national level, and the results cannot be used to generalize for female swimmers or for all strokes. Swimmers that are not front crawl specialist might not have the same efficiency in front crawl as in their specialty stroke, with a flatter slope$_{LV}$ in front crawl than in the specialty stroke. This could account for the results of the post hoc analysis where mean slope$_{LV}$ was not statistically significant different between Level 2 and Level 3, nor between Level 3 and Level 4 ($t [51] = 2.56; p=0.035$ and $t [51] = 1.62; p=0.247$ respectively).

### 4.2 Slope$_{LV}$ as a key performance indicator

To account for gender, differences in body size and specialty stroke, the swimmers were matched up as close as possible to investigate the hypothesis that slope$_{LV}$ is the key performance predictor, where Level 2 swimmers would have higher efficiency, i.e., steeper slope$_{LV}$ (lower negative value of slope$_{LV}$), than Level 3 swimmers. The hypothesis was rejected, as slope$_{LV}$ was not significantly different between Level 2 and Level 3 swimmers ($t [9] = 1.42, p=0.188$). In only 4 of the 10 pairs did the swimmer in Level 2 have a steeper slope, i.e., higher efficiency, but in 6 of the pairs the Level 2 swimmers had higher force capacity than their Level 3 counterparts. Force capacity, or $L_0$, was near significantly different ($t [9] = 2.11, p=0.064$) and seem to be the better performance indicator for this set of swimmers. The small sample size for testing the hypothesis, with only 10 pairs of like swimmers, reduces the power of this study and could lead to Type II error, thus erroneously rejecting the hypothesis.

These findings nevertheless indicate that at least for these swimmers, neither slope$_{LV}$ nor $L_0$ are predictors of performance level on their own. As the paired comparisons show, a high $V_0$ can be achieved either by high $L_0$ or by a steeper slope$_{LV}$ (higher efficiency) or by a balance between the two that best suits the individual swimmer. In 8 of the 10 pairs Level 2 swimmers had the highest $V_0$, in one pair they had equal $V_0$, and in one pair the Level 3 swimmer had
the higher \( V_0 \). In the two cases where Level 3 swimmers had equal or higher \( V_0 \), the Level 3 swimmer had a higher efficiency but lower force capacity than the Level 2 swimmer, implying the importance of efficiency. In 3 of the 10 pairs, the Level 3 swimmer had a higher force capacity than the Level 2 swimmer, but the Level 2 swimmer had a higher efficiency (steeper slope) and thus higher \( V_0 \), which further strengthens the importance of efficiency.

A couple of factors might influence the L-V profile of a swimmer, that affects the steepness of slope\(_{L,V}\). The technical ability to apply force propulsively could be affected if the third and heaviest load of the semi-tethered tests is too heavy for the swimmer, such that the swimmer adjusts the technique in a similar fashion as when fully tethered (Samson et al., 2019). Furthermore, fatigue impacts both force capacity and efficiency (Morin et al., 2011b), and even though all swimmers in this study were in the same preparatory training phase there could be large individual differences how fatigued a swimmer was during the testing session. If a swimmer is unable to reach maximum velocity during one of the swims the slope of the regression line could be shifted such that the efficiency appears better or worse than it actually is.

There are other possible factors other than the ones mentioned above, that could impact the outcome of the L-V profile test. The event distance that the swimmer specializes in is one such factor as force capacity would be of greater importance for a sprinter, and efficiency more important to a long distance swimmer (Barbosa, 2018). Another factor could be the number of years of higher level competitive experience of the swimmer but this would be more speculative as a swimmer could reach international elite level with few years of experience and another could be at the national elite level with many years of experience. A swimmer’s mental readiness or attitude toward the tests could also impact the outcome simply by not reaching maximum velocity during the first trial, thus shifting the slope.

Another illustration of the importance of efficiency in this study can be seen in the Level 2 L-V profiles for male swimmers (Figure 2a), where the swimmer with the highest \( V_0 \) of 2.05 m/s has a \( L_0 \) of 26.5 kg, whereas the second fastest swimmer with \( V_0 \) of 1.99 m/s has a much higher force capacity of 30.4 kg. For these tests the first swimmer can reach a higher velocity with less force, hence appears to be more efficient. The second swimmer actually has better PB100 than the first swimmer, indicating that either the second swimmer did not reach maximum velocity for the first trial thus flattening the slope (lower efficiency), or the first swimmer could not generate maximum force during the last trial thus making the slope
steeper (higher efficiency). Theoretically if the first swimmer improves his force capacity and maintains efficiency he will increase his maximum swimming velocity, and if swimmer two can maintain the high force capacity and improve his efficiency he will reach a higher swimming velocity. Similar examples of swimmer’s having different strategies to reach a high swim velocity was also seen in the Gonjo et al. (2021) study on front crawl performance and L-V parameters, further indicating that efficiency cannot be deemed the key performance indicator, but rather that each swimmer has his or her own strategy to best achieve a higher performance.

4.3 Relationship between L-V parameters and personal best

In an attempt to look further into the role of efficiency and force capacity without the performance level being a factor, all swimmers’ front crawl L-V parameters were compared to their personal best in 100 m front crawl. Personal bests achieved in LCM were used due to free-swimming velocity having a bigger impact on performance with less turns and underwater swimming moments, compared to SCM. With regards to efficiency this study found that the combination of predictors (slope$_{LV}$, rslope$_{LV}$, gender) was significantly related to PB100, and that slope$_{LV}$ and rslope$_{LV}$ significantly predicts PB100, but not gender. Regarding force capacity this study found the combination of predictors (L$_0$, rL$_0$, gender) were significantly related to PB100, but only L$_0$ significantly predicts PB100. Correlations have previously been found between peak propulsive force and velocity for 50m (Morouco et al., 2014), 100m (Rozi et al., 2018) and 200m (dos Santos et al., 2017) front crawl. Gonjo et al. (2021) found a very large significant relationship between efficiency and 50 m front crawl, but this study is a first look at how efficiency correlates to 100m front crawl. The ability to apply force is one aspect of efficiency, as simply being able to generate a lot of force is not enough to swim fast (Vorotzov et al., 2006; Dominguez-Castells et al., 2013; Santos et al., 2021). Finding the optimal balance between efficiency and force capacity for the individual seems to be the key to reaching high level of performance.

5 Practical implications

Coaches can use L-V profiles to monitor the progress of swimmers throughout the season if the same procedure and same settings are being used for each testing occasion. L-V profiling can also indicate if the swimmer needs more recovery, because if the swimmer cannot reach similar or better V$_0$ and/or L$_0$ of previous measurement then the swimmer might be on the
edge of overtraining or have other stressors that are impacting the ability to perform the 3x25m maximum effort test with ascending load. Doing these measurements throughout the season also provides insights to which capacity has improved by the prescribed training, and which capacity is the most limiting capacity for the swimmer.

6 Limitations

One limitation of this study is there was no maximum velocity measurement in free-swimming conditions to compare with $V_0$ from the semi-tethered tests. Being able to do a race simulation with a maximum effort swim from the starting block, with electronic timing equipment and synchronized filming would provide a true free-swimming condition maximum velocity that corresponds to what level of performance the swimmer is actually at during the testing occasion, rather than comparing to a swimmer’s personal best. This race simulation would also provide other variables that are important to a swimmer’s velocity capacity, such as stroke rate and stroke length.

Having groups with mixed gender and specialty stroke could be viewed as a limitation as they are factors that may influence the independent variables. It can also be viewed as a strength of the study as the sample represents the larger population of swimmers. Another possible limitation is that height and BM were the only anthropometric variables that were collected. More anthropometric variables could have been collected for a more comprehensive analysis of which parameter is a predictor of performance.

7 Conclusions

Efficiency was not found to be the key performance indicator between matched international elite and national elite swimmers in this study ($t [9] = 1.42; p=0.188$), and neither was force capacity ($t [9] = 2.11, p=0.064$), implying that neither can predict performance on its own. Nevertheless, a significant difference was found between the performance level groups, for all front crawl L-V profile parameters. Post hoc analyses however, indicated no significant difference between adjacent performance levels neither in $L_0$ nor slopeL.V. At the individual level a medium to strong relationship was found between the L-V parameters and the swimmer’s PB100.
All these findings imply that efficiency and force capacity cannot predict performance on their own, but rather swimmers use different strategies with these capacities to reach a higher level of performance.

These findings suggest that L-V profiling is best used to assess force capacity and efficiency for each individual swimmer, and as a way to monitor that the swimmer improves in the capacity that is needed the most to reach faster swim velocity. Further research with larger sample sizes for each Level, could provide insights into whether there is any preferred approach to reach a higher $V_0$ – higher force capacity or higher efficiency.

**8 Acknowledgements**

This study would not have been realized if it was not for the generous help of Stellan Kjellander and Niklas Harris at Malmö Idrottsakademi, providing me with a 1080 Sprint device to collect data with. Nor would this study have come to fruition if it was not for Prof. Bjørn Harald Olstad at Norwegian School of Sport Sciences (NIH), teching me about load-velocity profiling, letting me be a part of his larger L-V project, giving me advise and being a great support throughout the project. My deepest gratitude to Bjørn Harald for helping me accomplish this project. Special thanks to my supervisor Prof. Nikolai Bastrup Nordsborg, Head of NEXS department at University of Copenhagen, who has helped me stay on course, aided with Danish translations, and provided valuable feedback for me to finish this thesis with focus and intent.
References


## Appendix 1

### Literature search

### Purpose and questions to answer:

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<td>load-velocity profile, hydrodynamic forces, force-velocity, force in swimming, tethered force measurements, drag force, propulsive force,</td>
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### Search words and phrases used

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<td>Requested articles directly from authors</td>
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### Where and how searches were performed

### Comments

After reading a relevant article that was used as a reference I would search for specific articles that were refered to in the relevant article that were of importance for my study. This was done either/or on ResearchGate and PubMed. If an article was hard to find I requested it from the author via ResearchGate (did get about 8 articles that way)
Appendix 2

Informed consent form (Danish)

ANMODNING OM DELTAGELSE I ET FORSKNINGSPROJEKT
BESTEMMENDE FAKTORER FOR YDEEVNE I SVØMNING – LOAD-VELOCITY PROFILERING AF CRAWL

Dette er en invitation til deltagelse i et kandidatspeciale og forskningsprojekt, der vil fokusere på load-velocityprofilering af frontcrawl, som vil være en del af en større igangværende undersøgelse om præstationsbestemmende faktorer ved svømning på NIH (Norges idrettshøgskole) i Oslo, i samarbejde med GIH (Stockholm) og Københavns Universitet. I dette dokument er der information om projektets mål og hvad din deltagelse vil betyde for dig. Ydeevne i svømning er afhængig af mange faktorer, såsom fysisk kapacitet (styrke, udholdenhed og mobilitet), antropometri, mentale faktorer, tekniske færdigheder og taktik. Overordnet vil vi se på, hvordan disse faktorer hænger sammen og påvirker hinanden, afhængigt af køn og træningsstatus. Hvilke parametre, der er vigtigst for forskellige svømmetag og distancer, er et andet emne, der vil blive undersøgt yderligere.

Bjørn Harald Olstad (bjornho@nih.no, +47 930 61 946) er leder af det større projekt på NIH, og kandidatstuderende Maria Vitazka (GIH; coach.vitazka@gmail.com, +46 725 164499) vil udføre de tests, der er relevante for denne specifikke del af projektet, samt analyseres og rapportere resultaterne. Ved at deltage i dette projekt accepterer du samtidig, at dine data (resultater og målinger fra dette specifikke projekt) kan videregives til samarbejdende forskere i det overordnede projekt. Dog vil deling af data være anonymt, da en ID/kode vil blive tildelt dine data. Denne deling af data sker kun, når vi finder det hensigtsmæssigt at kunne besvare forskningsspørgsmålene bedst muligt. Til denne specifikke undersøgelse har vi brug for både mandlige og kvindelige konkurrencesvømmere på forskellige niveauer – national elite og international elite (bestemt af FINA-point).

Hvis du har læst oplysningerne og ønsker at deltage i undersøgelsen, bedes du underskrive i bunden af denne samtykkeerklæring og returnere den til forskeren (Maria Vitazka). Du kan til enhver tid trække dig og dine data fra denne undersøgelse.

HVAD INDEHOLDER PROJEKTTET?
I dette kandidatforskningsprojekt vil vi indsamle og registrere personlige oplysninger såsom navn, fødselsdato, køn, højde, vægt (kun til bestemmelse af load), PR og FINA-point. Da
dette projekt er en tværsnitsundersøgelse, der ser på individers kapacitet, vil der kun være én forøgsrunde. De indsamlede oplysninger vil blive registreret elektronisk og forblive anonyme.

Hvor stærk du er ved forskellige hastigheder eller modstande vil blive testet ved forsøg, hvor du er knyttet til et spil/motor (billede 1), der kan måle din styrke ved forskellige hastigheder eller den hastighed, du formår at udvikle ved forskellige modstande. Vi kan også måle variationer i hastighed og styrke inden for og mellem svømmecyklusser. I disse tests vil du have et bælte om din talje med en snor påsat (billede 2). Testene udføres ved svømning med maksimal indsats i ca. 25 meter. Der er minimum 4 minutters pause mellem hvert forsøg, og der vil blive udført i alt 3 forsøg med stigende belastning. Den første af de 3x25m vil være med 1 kg belastning, den tredje tur vil være på 10 % af kropsmassen (hvilket betyder individualiseret belastning), og den anden tur vil være belastningen i midten af 1 kg og 10 % af kropsmassen. Frontcrawl er den stil, der vil blive testet. Efter lidt restitutionssvømning (ca. 30 min) vil der være mulighed for hver svømmer med en anden specialedisciplin end freestyle, for også at blive testet med samme protokol (3x25m maksimal indsats med stigende belastning) for deres disciplin.

**Billede 1**

**Billede 2**

**MULIGE FORDELE OG ULEMPER**

Ved at deltage i dette projekt får du indsigt i, hvordan forskningen foregår og har mulighed for at udføre avancerede test og målinger, som normalt er dyre. Du kan også bruge disse resultater til at arbejde på de faktorer, som du skal forbedre, i din daglige trening, så du kan blive en bedre svømmer. Load-velocity testene er ret hurtige at udføre, og med rigelig hvile mellem hvert forsøg (4-5 minutter) belaster testene ikke kroppen for meget. Et vigtigt aspekt er indsatsen – du skal svømme maksimalt i alle 3 forsøg for at få en pålidelig og valid load-velocity profil.
FRIVILLIG DELTAGELSE OG MULIGHED FOR AT TILBAGE SAMTYKKE

GDPR - HVAD SKER DER MED OPLYSNINGERNE OM DIG?

Dine rettigheder
Så længe du kan identificeres i datamaterialet, har du ret til:
- adgang til de personoplysninger, der er registreret om dig
- at få rettet personoplysninger om dig,
- at få sletted personlige data om dig,
- at få udleveret en kopi af dine personlige data (dataportabilitet)

**GODKENDELSE**

NSD - Norsk Center for Forskningsdata AS har på vegne af Norges Idrætshøjskole vurderet, at behandlingen af personoplysninger i dette projekt er i overensstemmelse med privatlivsbestemmelserne (referencenummer 92250). Forskningsetikken i forbindelse med undersøgelsen er blevet behandlet og godkendt af den interne etiske komité ved Norges Idræts- og Idrætsuniversitet (sagsnummer 47).

Protokollen blev evalueret af den lokale danske etiske komité, og procedurerne blev fundet i overensstemmelse med national lovgivning (Ref F-23006844)

**SAMTYKKE TIL DELTAGELSE I PROJEKTET**

Jeg har modtaget information om undersøgelsen og er villig til at deltage.

<table>
<thead>
<tr>
<th>Dato og sted</th>
<th>Deltagere underskrift</th>
</tr>
</thead>
<tbody>
<tr>
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</table>

**VÆRGES SAMTYKKE OM DELTAGELSE I PROJEKTET**

*(for svømmere under 18 år)*

Jeg har modtaget information om projektet og som svømmerens værge godkender jeg deltagelse i projektet

<table>
<thead>
<tr>
<th>Dato og sted</th>
<th>Værge underskrift</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

| Deltagere navn med blokbogstaver | Værge navn med blokbogstaver |