Physiological, biomechanical and anthropometrical predictors of sprint swimming performance in adolescent swimmers

Evelin Lätt 1,2, Jaak Jürimäe 1, Jarek Mäestu 1, Priit Purge 1, Raul Rämson 1, Kaja Haljaste 1, Kari L. Keskinnen 2, Ferran A. Rodriguez 3 and Toivo Jürimäe 1

1 Faculty of Exercise and Sport Sciences, Institute of Sport Pedagogy and Coaching Sciences, University of Tartu, Tartu, Estonia, 2 Finnish Society of Sport Sciences, Helsinki, Finland, 3 Institució Nacional d’Educació Física de Catalunya, Sport Sciences Research Group, Universitat de Barcelona, Barcelona, Spain

Introduction

Certain anthropometric characteristics must be taken into consideration in analysing sprint swimming performance, including body height, arm span and lean body mass (Jürimäe et al., 2007; Strzala and Tyka, 2009). These somatic attributes are largely inherited and determine swimming technique to a high degree. However, data on the relationship among anthropometric properties, physical capacity and sprint swimming performance in adolescent swimmers are scarce. Since metabolic capacities as well as skill acquisition, are affected by growth and development (Malina, 1994), it can be suggested that factors predicting swimming performance may vary for young swimmers and may be different compared to adults. In fact, Geladas et al. (2005) found that total upper extremity length, leg power and handgrip strength could be used as predictors of 100-m front crawl performance in 12-14 year-old boys. A multivariate analysis of swimming performance in a large sample (n = 66) of male swimmers (11-12 years) of high national level found that predictive variables pertaining to the anthropometric (sitting height), physiological (aerobic speed and endurance) and technical (swimming index) domains explained 82.4% of competitive performance (Saavedra et al., 2010). Overall, it appears that somatic traits play an important role in swimming performance during the years of growth.

Energy cost is a key parameter to evaluate performance in swimming and it has been described as a predictor of performance in human locomotion, in both terrestrial and aquatic environments (di Prampero, 1986; Zamparo et al., 2005b). Traditionally, the energy cost of swimming (Cs) is defined as the total energy expenditure required for displacing the body over a given unit of distance (di Prampero et al., 1986; Pendergast et al., 2003). Kjendlie et al. (2004a) reported significantly lower energy cost in children (12-year-old boys) than in adults (21-year-old males) at comparable swimming velocity, thus confirming the results obtained by Ratel and Poujade (2009) in a group of 12-13 year-old boys and 18-22 year old men. Cs increases as a function of velocity (Capelli et al., 1998; Poujade et al., 2002) and has usually been assessed from the ratio of oxygen uptake (VO2) to the corresponding velocity (v) in swimmers (Kjendlie et al., 2004a). When calculating Cs based in the VO2 and velocity, there are two ways to computing that. Some researchers use VO2-v3 to illustrate Cs, with linear function (Kjendlie et al., 2004a; 2004b), but the common use is VO2-v (curvilinear function) (Barbosa et al., 2008; Capelli et al., 1998; Poujade et al., 2002; Zamparo et al., 2005a). However, it is also important that anaerobic metabolism is also taken into account (Barbosa et al. 2005b, Barbosa et al., 2006), since its relatively higher contribution during 100-m distance.

The recent development of improved instrumenta- tion and technology in breath-by-breath analysis has resulted in new approaches to study VO2 also in aquatic environments. The last generation of miniaturized breath-by-breath metabolic carts can be used in combination of newly developed snorkels to directly measure cardiorespiratory parameters during swimming with acceptable accu-
racy and reliability (Keskinen et al., 2003; Rodriguez et al., 2008). This instrumentation has also been used to characterize VO₂ kinetics during free swimming (Barbosa et al., 2006; Rodriguez et al., 2003). However, no studies using breath-by-breath gas analysis have been conducted to determine oxygen consumption and Cₛ during sprint swimming in adolescent swimmers.

The understanding of the behavior of stroke mechanics and its relationship to vₛ is one of the major points of interest in biomechanical research in swimming (Keskinen and Komi, 1993; Kjendlie et al., 2006; Toussaint et al., 2006). Increases or decreases in vₛ are due to a combined increase or decrease in stroke rate (SR) and stroke length (SL) (Keskinen and Komi, 1993; Toussaint et al., 2006). Stroke mechanics is considered to reach an optimal balance between SR and SL when vs values are at their highest level with a relatively low Cs (Barbosa et al., 2008). It has been shown that increases in maximal vₛ from the age of about 11 are related to increased SL, while SR at maximal vₛ does not increase with age (Kjendlie et al., 2004b). According to the literature, at a given vₛ, Cs significantly increases with increasing SR (Barbosa et al., 2005a; Zamparo et al., 2005b). Less consistent is the decrease of Cₛ with increasing SL (Barbosa et al., 2005a; Costill et al., 1985; Pendergast et al., 2003; Zamparo et al., 2005b). High stroke index (SI) values are strongly associated with low Cs (Costill et al., 1985). In this sense, and following the referred authors, SI can also be used as an overall estimation of swimming efficiency.

To our knowledge, no studies have investigated the influence of different anthropometric, physiologic and technical parameters together to determine sprint swimming performance in young swimmers. There is also lack of studies using breath-by-breath technology, and thus being able to characterize oxygen consumption, in during swimming in adolescent swimmers. Accordingly, the purpose of this study was to investigate the contribution of different anthropometrical, physiological and biomechanical parameters to sprint swimming performance in adolescent boys. We hypothesis that sprint swimming performance at that young age could be predicted from a relatively low number of selected variables pertaining to these three testing domains.

Methods

Participants
Twenty-five adolescent male swimmers (15.2 ± 1.9 years) participated in the study. All swimmers had a training background of 5.6 ± 1.5 years and over the last two years they had been practicing for 5.6 ± 1.5 h/week. Swimmers were recruited from local swimming clubs on a voluntary basis. Biological age was measured according to the method of Tanner (Tanner and Whitehouse, 1976), which uses self-assessment of genitalia development and pubic hair stage in boys. The participants were given photographs, figures and descriptions, and asked to choose the one that most accurately reflected their appearance. This study was approved by the Medical Ethics Committee of the University of Tartu. All swimmers and their parents were informed of the purposes and methods of the study and a written informed consent was obtained from the parents before participation.

Procedures
Test and assessments were conducted on two different occasions during the study period. On a first visit, anthropometrical parameters and biological age were assessed. The same day, a second testing session consisted of an all-out 100-m front crawl swimming test in the pool. On a second day, body composition parameters were measured.

Anthropometry and body composition
Body height was measured to the nearest 0.1 cm using a Martin’s anthropometer, body mass (kg) was measured to the nearest 0.05 kg using calibrated medical balance scales (A&D Instruments Ltd., UK), and body mass index (BMI; kg·m⁻²) was then calculated. In addition, arm span was measured to the nearest 0.1 cm Anthropometrical assessments were performed by internationally certified ISAK level 1 anthropometrist.

Body fat mass (kg), fat-free mass (kg), bone mass (kg), total bone mineral density (g·cm⁻²) and spine (L₁-L₄) bone mineral density (g·cm⁻²) were measured by DXA using the DPX-IQ densitometer (Lunar Corporation, Madison, WI, USA) equipped with proprietary software. The procedure was conducted by a qualified radiologist. Coefficient of variation (CV) for measured body fat mass, fat-free mass, bone mass and bone mineral density values was less than 2%.

Maximal swimming test
The Cₛ of swimming, peak oxygen uptake in swimming (VO₂peak) and stroking parameters were assessed during an all-out 100-m front crawl test performed in 25-m swimming pool. Restricted as they were by the gas sampling devices, the swimmers started without diving from the wall and did not perform regular turning motions at the end of the lane but instead resumed swimming immediately without gliding underwater after the turn. Turns were made to the same lateral side at both ends of the pool to avoid distortion of the gas analyser’s sampling line. Swimmers performed a 400-m warm-up swim, followed by a 10 min passive resting period before the 100-m all-out trial. A respiratory snorkel and valve system with low hydrodynamic resistance was used to collect breathing air samples (Keskinen et al., 2003; Rodriguez et al., 2008; Toussaint et al., 1987) and was connected to a telemetric portable breath-by-breath gas analyzer (Metamax-3B, Cortex, Leipzig, Germany) (Aspenes et al., 2009). Values were averaged for 10-s periods. The respiratory device, connected to a portable gas analyzer of similar technical characteristics (K4 b², Cosmed, Italy) has demonstrated good validity and accuracy (Keskinen et al., 2003; Rodriguez et al., 2008) and has been used in recent published works (Barbosa et al., 2005a; Rodriguez et al., 2003). Swim performance was assessed from the time spend in seconds. The swimmers were familiarized with the snorkel by letting them swim 100-m at moderate speed with the breathing apparatus preceding the maximal trial.

Capillary blood samples for the measurement of blood lactate concentration (La; mmol·L⁻¹) were taken...
from the fingertip pre exercise and at the third (La₃) and fifth (La₅) minute during the recovery period (Capelli et al., 1998) and analysed using an enzymatic photometric method (Lange Microanalyzer, Lange GMBH, Berlin, Germany). The net increase of blood lactate concentration (∆La) was obtained by subtracting the pre-trial value from the peak value attained during the recovery phase.

To exclude the influence of turning and starting, the average swimming velocity (vs; m/s) attained by each swimmer during the trial was measured over 15 m within two points 5.0 m apart from each end of the pool (vs = D/t15, where D = 15 m and t15 = time for the 15-m distance) (Poujade et al., 2002; Zamparo et al., 2005a).

Swimming velocity and stroking parameters were measured by means of time video analysis (Huot-Marchand et al., 2005), by two independent evaluators. SR (cycles·min⁻¹) was calculated as the average number of strokes completed by the swimmers during the 15-m distance (Poujade et al., 2002). One SR cycle being defined as the time between the entry of one hand until the following entry of the same hand (Huot-Marchand et al., 2005). SL (m·cycle⁻¹) was calculated as the ratio between average velocity and the corresponding SR (Poujade et al., 2002). SI (m²·sec⁻¹·cycle⁻¹) was calculated by multiplying swimming velocity by SL (Costill et al., 1985). Total energy expenditure (Etot, mL·O₂·kg⁻¹·min⁻¹) corrected for body mass was calculated using the net VO₂ (i.e. difference between the value measured at the end of the 100 m trial and the resting value), and the oxygen energy equivalent of net blood lactate concentration (i.e. difference between the value measured at the end of the task and the resting value) (Rodriguez 1999). The VO₂ energy equivalent was assumed to be 2.7 mL·O₂·kg⁻¹·min⁻¹, as that proposed by di Prampero et al. (1978) for competitive swimming. Cs was calculated as the ratio between Etot and vs (mL·O₂·m⁻³), and then converted into the SI units (kJ·m⁻¹) by assuming that 1 mL·O₂ is equivalent to 20.1 J (di Prampero et al., 1986; Pendergast et al., 2003).

**Statistical analysis**

The normality of distribution was assessed on all data using the Kolmogorov-Smirnov test. Means, standard deviations, minimum and maximum values were calculated for all parameters (Table 1). Partial correlation coefficients (rp) with age as control variable were used to determine the degree of association between assessment variables and swimming performance. For each type of assessment backward stepwise linear regression analyses were used to assess the potential relationships with swimming performance and to evaluate which group of parameters (i.e., anthropometrical, physiological, biomechanical) best characterized swimming performance. Additionally, multiple linear regression (MLR) models using the backward stepwise procedure were developed entering all variables.

A p-value ≤ .05 was considered to be statistically significant. SPSS for Windows, version 13.0; (SPSS Inc.; Chicago, IL) was used for all analyses.

**Results**

Mean (± SD) 100-m performance time was 77.6 ± 9.1 s. The average vs without gliding start and turnings was 1.34 ± 0.14 m·s⁻¹. Descriptive statistics for anthropometrical, physiological and biomechanical parameters and their relationship with 100- front crawl performance time with age as control variable are presented in Table 1. Partial correlation analysis showed that swimming performance was significantly correlated (p < .05) with body height, bone mass, spine bone mineral density and arm span

**Table 1. Anthropometrical, physiological and biomechanical parameters and their correlation with 100-m front crawl swimming performance in adolescent swimmers (n = 25). Data are means (± standard deviations, SD), minimal and maximal values, and partial correlation coefficients (rp) with age as control variable.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>min</th>
<th>max</th>
<th>Partial correlation with 100-m time (rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body height (cm)</td>
<td>1.76 (.09)</td>
<td>1.52</td>
<td>1.89</td>
<td>-.536 *</td>
</tr>
<tr>
<td>Body mass, BM (kg)</td>
<td>63.3 (10.9)</td>
<td>45.0</td>
<td>89.0</td>
<td>-.480</td>
</tr>
<tr>
<td>Body mass index, BMI (kg·m⁻²)</td>
<td>20.2 (2.2)</td>
<td>15.6</td>
<td>24.9</td>
<td>-.247</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>12.8 (3.3)</td>
<td>7.5</td>
<td>18.4</td>
<td>.061</td>
</tr>
<tr>
<td>Total body fat mass, (kg)</td>
<td>8.0 (2.2)</td>
<td>4.1</td>
<td>11.6</td>
<td>-.174</td>
</tr>
<tr>
<td>Fat-free mass, (kg)</td>
<td>54.7 (9.6)</td>
<td>39.0</td>
<td>77.4</td>
<td>-.506</td>
</tr>
<tr>
<td>Bone mass, (kg)</td>
<td>2.7 (.6)</td>
<td>1.60</td>
<td>3.84</td>
<td>-.543 *</td>
</tr>
<tr>
<td>Total bone mineral density, (g·cm⁻²)</td>
<td>1.12 (.10)</td>
<td>.95</td>
<td>1.33</td>
<td>-.462</td>
</tr>
<tr>
<td>Spine bone mineral density, (g·cm⁻²)</td>
<td>1.06 (.15)</td>
<td>.79</td>
<td>1.28</td>
<td>-.516 *</td>
</tr>
<tr>
<td>Arm span (cm)</td>
<td>182.8 (11.5)</td>
<td>152.5</td>
<td>200.5</td>
<td>-.557 *</td>
</tr>
<tr>
<td>Velocity, vs (m·s⁻¹)</td>
<td>1.34 (14)</td>
<td>1.01</td>
<td>1.57</td>
<td>-.938 *</td>
</tr>
<tr>
<td>Stroke length, SL (m·cycle⁻¹)</td>
<td>1.00 (.09)</td>
<td>.84</td>
<td>1.22</td>
<td>-.506</td>
</tr>
<tr>
<td>Stroke rate, SR (cycle·min⁻¹)</td>
<td>40.2 (2.9)</td>
<td>35.0</td>
<td>46.0</td>
<td>-.785 *</td>
</tr>
<tr>
<td>Stroke index, SI (m²·sec⁻¹·cycle⁻¹)</td>
<td>1.35 (.24)</td>
<td>.85</td>
<td>1.83</td>
<td>-.643 *</td>
</tr>
<tr>
<td>VO₂peak (L·min⁻¹)</td>
<td>3.51 (.82)</td>
<td>2.31</td>
<td>5.72</td>
<td>-.398</td>
</tr>
<tr>
<td>VO₂peak (ml·min⁻¹·kg⁻¹)</td>
<td>55.2 (5.9)</td>
<td>44.4</td>
<td>70.6</td>
<td>-.017</td>
</tr>
<tr>
<td>AVO₂ (L·min⁻¹)</td>
<td>3.02 (.79)</td>
<td>1.86</td>
<td>5.31</td>
<td>-.322</td>
</tr>
<tr>
<td>La₃ (mmol·L⁻¹)</td>
<td>6.40 (2.81)</td>
<td>2.64</td>
<td>14.20</td>
<td>-.525 *</td>
</tr>
<tr>
<td>La₅ (mmol·L⁻¹)</td>
<td>6.58 (3.03)</td>
<td>2.65</td>
<td>14.20</td>
<td>-.574 *</td>
</tr>
<tr>
<td>Blood lactate accumulation, ∆La (mmol·L⁻¹)</td>
<td>4.9 (3.0)</td>
<td>0.61</td>
<td>12.6</td>
<td>-.598 *</td>
</tr>
<tr>
<td>Energy cost of swimming, Cs (kJ·m⁻¹)</td>
<td>3.99 (1.78)</td>
<td>1.31</td>
<td>8.50</td>
<td>-.544 *</td>
</tr>
<tr>
<td>Tanner sexual maturation stage (1-5)</td>
<td>3.9 (1.02)</td>
<td>2</td>
<td>5</td>
<td>-.285</td>
</tr>
</tbody>
</table>

* Statistically significant correlation (p < .05); † controlled also for swimming velocity
Aim
This study investigated the contribution of different anthropometrical, physiological and biomechanical parameters to sprint swimming performance in adolescent boys. The main findings are: 1) that biomechanical factors may explain 90.3% of the variance in 100-m swimming performance 2) that anthropometrical (45.8%) and physiological (45.2%) parameters were also strongly related to 100-m swimming performance 3) that the best single predictor of 100-m swimming performance in these adolescent male swimmers. Previous studies have shown that SI is strongly related to swimming performance in adolescent swimmers also in longer distances (Jürimäe et al., 2007; Lätt et al., 2009b), as well as a good predictor of overall competitive performance (Saavedra et al., 2010). Therefore, it seems important to emphasize the importance of teaching and learning the correct swimming technique from the early years of swimming training, regardless of the event. Marino et al., 2010 also recommended that specific training sets concerning technique correction and improvement in young swimmers might be a main aim during training planning in swimming.

Discussion
This study investigated the contribution of different anthropometrical, physiological and biomechanical parameters to sprint swimming performance in adolescent boys. The main findings are: 1) that biomechanical factors may explain 90.3% of the variance in 100-m swimming performance 2) that anthropometrical (45.8%) and physiological (45.2%) parameters were also strongly related to 100-m swimming performance 3) that the best single performance predictors were SI, arm span and ∆La; and 4) that two selected variables included in the MLR model for all variables (SI and SR) explained 92.6% of the variance in 100-m swimming performance in this adolescent swimmers.

Few studies have investigated the relationship of different biomechanical and physiological parameters to 100-m front crawl performance in adolescent swimmers (Kjendlie et al., 2004a; 2004b). Swimmers start heavy trainings at relatively young age therefore, it is important to assess which parameters may be the best predictors of sprint swimming performance. This enables consideration of specific parameters when predicting success and planning specific training programs in young swimmers.

The obtained SR values (40.1 ± 2.8) were in relatively same range as found in other studies (Dekerle et al., 2002; Fernandes et al., 2008; Strzala and Tyka, 2009). However, even SR parameters can not be easily compared since most studies have not used respiratory snorkel that, due to some resistance, has the impact on SL. In elite swimmers using respiratory snorkel, SL was significantly higher compared to our study (Dekerle et al., 2005; Fernandes et al., 2008). However, their subjects were also significantly older (19 years vs 15 years, respectively).

The present investigation showed that biomechanical parameters (SI and SR) are close correlates of 100-m swimming performance, SI being the best single predictor of 100-m swimming performance in these adolescent male swimmers. Previous studies have shown that SI is strongly related to swimming performance in adolescent swimmers also in longer distances (Jürimäe et al., 2007; Lätt et al., 2009a; 2009b), as well as a good predictor of overall competitive performance (Saavedra et al., 2010). Therefore, it seems important to emphasize the importance of teaching and learning the correct swimming technique from the early years of swimming training, regardless of the event. Marino et al., 2010 also recommended that specific training sets concerning technique correction and improvement in young swimmers might be a main aim during training planning in swimming.

C is one of the commonly used parameter to predict the swimming performance (Kjendlie et al., 2004a; Poujade et al., 2002; Zamparo et al., 2005b). In this study we measured VO2 using modern procedures for collecting and measuring breath-by-breath expired gas, which allowed the characterization of VO2 kinetics during swimming exercise. This method has been found suitable for assessing swimming performance in young swimmers (Keskinen et al., 2003; Kjendlie et al., 2004a; Ratel and Poujade, 2009; Rodriguez et al., 2008). VO2 parameter at similar age subjects has not been extensively studied. The obtained VO2peak values in this study were in the same range as in Strzala et al. (2005), where VO2 values were measured during 100-m distance in adolescents Tanner stage 4-5. However, they measured oxygen consumption on cycle ergometer (Strzala et al. 2005). Two other studies (Dekerle et al., 2005; Fernandes et al., 2008) measured VO2 in the pool, but their subjects were older (19 years old) and at higher level, that resulted in high VO2peak Values (> 70 ml/min·1.4·kg−1). C is a key parameter to evaluate performance in swimming, but there are only a few studies that have investigated the determinants of C in

<table>
<thead>
<tr>
<th>Variables</th>
<th>Variables entered in model</th>
<th>R2</th>
<th>Adjusted R2</th>
<th>t</th>
<th>p</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomechanical</td>
<td>SR, SI</td>
<td>.911</td>
<td>.903</td>
<td>19.902</td>
<td>.000</td>
<td>(2;24) = 112.87</td>
<td>.000</td>
</tr>
<tr>
<td>Anthropometrical</td>
<td>Arm span, height, bone mass, spine bone mineral density</td>
<td>.559</td>
<td>.458</td>
<td>4.115</td>
<td>.001</td>
<td>(4;16) = 5.503</td>
<td>.012</td>
</tr>
<tr>
<td>Physiological</td>
<td>∆La, La3, La5, C</td>
<td>.551</td>
<td>.452</td>
<td>4.558</td>
<td>.000</td>
<td>(4;22) = 5.531</td>
<td>.004</td>
</tr>
<tr>
<td>In all variables</td>
<td>SR, SI</td>
<td>.936</td>
<td>.926</td>
<td>16.867</td>
<td>.000</td>
<td>(2;15) = 94.412</td>
<td>.000</td>
</tr>
</tbody>
</table>
children and adolescents (Kjendlie et al., 2004a; Poujade et al., 2002). Previous investigations have found relationships between $C_s$ and body height, body mass and arm span in adolescent swimmers (Jürimäe et al., 2007; Lätt et al., 2009b; Ratel and Poujade, 2009), but this was not the case in our study, where no relationships between anthropometrical parameters and $C_s$ were found.

In sprint swimming $v_s$ seems to depend mainly on anaerobic capacity and swimming efficiency in adolescent swimmers (Strzala and Tyka, 2009), although peak $VO_2$ has also been found to significantly correlated with 100-m speed ($r = .787$) in adult swimmers (Rodriguez et al., 2003). In our study $C_s$ was significantly related to $La_3$, $La_5$ and $ΔLa$, but not to $VO_{peak}$ or $ΔVO_2$ value. This may be explained by the fact that $C_s$ is calculated based on both aerobic and anaerobic energy expenditure (Barbosa et al., 2005b; 2006; di Prampero et al., 1986). We suggest that swimming in our study was performed quite extensively in anaerobic zone and thus general $C_s$ relied mostly on the anaerobic energy metabolism. The fact that $C_s$ is related to the $VO_2$ may be due to the role of the anaerobic processes to the total energy expenditure, which is not always taken into account or is obviously less important when longer distances are used. The relative contribution of this bioenergetical system to the overall energy expenditure should not be disregarded (Camus and Thys, 1991). Strzala and Tyka (2009) also found that a large contribution of anaerobic energetic processes in sprint efforts leads to high post-exercise blood lactate concentration. Sprint events are heavily reliant on the anaerobic energy processes, but children's ability to generate energy via this system is limited (Taylor et al., 2003; Lätt et al., 2009b; Ratel and Poujade, 2009), but this was not the case in our study, where no relationships between anthropometrical parameters and $C_s$ were found.

Conclusion

Present results indicate that biomechanical factors (90.3%) explained most of 100-m front crawl swimming performance variability in these adolescent male swimmers, followed by anthropometrical (45.8%) and physiological (45.2%) parameters. $SI$ was the best single predictor of performance, while arm span and $ΔLa$ were the best anthropometrical and bioenergetical indicators, respectively. $SI$ and $SR$ alone explained 92.6% of the variance in competitive performance. To take into account these results, it is of utmost importance to consider specific stroke technique parameters when predicting success in young swimmers.

Acknowledgements

The authors would like to thank the participants and their coaches for their commitment during this study.
References


relation to 100 and 400m time trials in young swimmers. *Journal of Human Kinetics* 14, 105-116.


**Key points**

- This study investigated the influence of different anthropometrical, physiological and biomechanical parameters on 100-m swimming performance in adolescent boys.
- Biomechanical factors contributed most to sprint swimming performance in these young male swimmers (90.3% of variability in performance), followed by anthropometrical (45.8%) and physiological (45.2%) parameters.
- Two selected variables (stroke index and stroke rate) explained 92.6% of the variance in competitive performance in these adolescent swimmers.

**AUTHORS BIOGRAPHY**

**Evelin Lätt**

**Employment**
PhD student on Faculty of Exercise and Sport Sciences, University of Tartu, Estonia

**Degree**
MSc

**Research interest**
Swimming biomechanics and bioenergetics

**E-mail:** evelin.latt@ut.ee

**Jaak JÜRIMÄE**

**Employment**
Professor on Faculty of Exercise and Sport Sciences, University of Tartu, Estonia

**Degree**
PhD

**Research interest**
Exercise physiology, coaching sciences

**E-mail:** jaak.jurimae@ut.ee

**Priit PURGE**

**Employment**
Research fellow on Faculty of Exercise and Sport Sciences, University of Tartu, Estonia

**Degree**
PhD

**Research interest**
Exercise physiology, coaching sciences

**E-mail:** priit.purge@ut.ee

**Jarek MAESTU**

**Employment**
Research fellow on Faculty of Exercise and Sport Sciences, University of Tartu, Estonia

**Degree**
PhD

**Research interest**
Exercise physiology, coaching sciences, training monitoring

**E-mail:** jarek.maestu@ut.ee

**Toivo JÜRIMÄE**

**Employment**
Professor on Faculty of Exercise and Sport Sciences, University of Tartu, Estonia

**Degree**
PhD

**Research interest**
Exercise physiology, coaching sciences, body composition in children

**E-mail:** toivo.jurimae@ut.ee

**Kaja HALJASTE**

**Employment**
Lecturer on Faculty of Exercise and Sport Sciences, University of Tartu, Estonia

**Degree**
MSc

**Research interest**
Swimming training, training monitoring

**E-mail:** kaja.haljaste@ut.ee

**Kari L. KESKINEN**

**Employment**
Secretary-general on Finnish Society of Sport Science

**Research interest**
Swimming biomechanics, swimming energetic

**E-mail:** kari.keskinen@lts.fi

**Ferran A. RODRIGUEZ**

**Employment**
Professor on Department of Health and Applied Sciences

**Research interest**
Swimming performance analysis, swimming biomechanics

**E-mail:** farodriguez@gencat.cat

**Toivo JÜRIMÄE**

**Employment**
Professor on Faculty of Exercise and Sport Sciences, University of Tartu, Estonia

**Research interest**
Exercise physiology, coaching sciences, body composition in children

**E-mail:** toivo.jurimae@ut.ee

**Evelin Lätt**

Institute of Sport Pedagogy and Coaching Sciences, Faculty of Exercise and Sport Sciences, University of Tartu, 5 Jakobi Street 51014 Tartu, Estonia