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## The effect of different loads on semi-tethered swimming and its relationship with dry-land performance variables.

--Manuscript Draft--

<b>Full Title:</b>	The effect of different loads on semi-tethered swimming and its relationship with dry-land performance variables.
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<b>Abstract:</b>	<p>Semi-tethered loaded swimming (denoted STLS) has been used widely to develop or test swimmers skills, although its transference to increase performance seems overestimated. In addition, its relationship with dry-land tests remains obscured by imprecise reports. Sixteen competitive male swimmers (age: <math>18.31 \pm 1.42</math>) participated in a two-fold purpose study: Firstly, swimming performance was assessed at different STLS intensities on an adapted Smith Machine. A repeated measures 1-way ANOVA was conducted to find differences between the variables collected through a linear encoder at 15, 30, 45 and 60% of the maximal load (ML). Secondly, the relationships between the swimming velocities and the different sorts of variables obtained on a dry-land arm-stroke strength test were studied by Pearson's correlation coefficient (<math>r</math>). The results showed that less velocity, acceleration and impulse were delivered at high loads (<math>p &lt; 0.001</math>). It increased the velocity fluctuation, affecting the swimming patterns adversely. On the other hand, the correlations between velocity-based dry-land variables and swimming velocities (<math>r = 0.71</math>) seem to be more suitable to predict swimming performance, rather than strength-based variables (<math>r = 0.49</math>). In conclusion, coaches should reconsider using STLS, as little or no benefit may be obtained in performance.</p>
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1     **The effect of different loads on semi-tethered swimming and its relationship with**  
2                                     **dry-land performance variables.**

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43 **DISCLOSURE STATEMENT**

44 No potential conflict of interest was reported by the authors.

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46 **GEOLOCALIZATION INFORMATION**

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49 West longitude: 3° 35' 52.246"

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66    **ABSTRACT**

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68    Semi-tethered loaded swimming (denoted STLS) has been used widely to develop or test  
69    swimmers skills, although its transference to increase performance seems overestimated. In  
70    addition, its relationship with dry-land tests remains obscured by imprecise reports. Sixteen  
71    competitive male swimmers (age:  $18.31 \pm 1.42$ ) participated in a two-fold purpose study:  
72    Firstly, swimming performance was assessed at different STLS intensities on an adapted Smith  
73    Machine. A repeated measures 1-way ANOVA was conducted to find differences between the  
74    variables collected through a linear encoder at 15, 30, 45 and 60% of the maximal load (ML).  
75    Secondly, the relationships between the swimming velocities and the different sorts of variables  
76    obtained on a dry-land arm-stroke strength test were studied by Pearson's correlation coefficient  
77    ( $r$ ). The results showed that less velocity, acceleration and impulse were delivered at high loads  
78    ( $p < 0.001$ ). It increased the velocity fluctuation, affecting the swimming patterns adversely. On  
79    the other hand, the correlations between velocity-based dry-land variables and swimming  
80    velocities ( $r = 0.71$ ) seem to be more suitable to predict swimming performance, rather than  
81    strength-based variables ( $r = 0.49$ ). In conclusion, coaches should reconsider using STLS, as  
82    little or no benefit may be obtained in performance.

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84    **KEY WORDS:** Swimming power; Performance assessment; Strength; Dry-land

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90    **INTRODUCTION**

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92    The development of strength is crucial in swimming competition (Vorontsov, Seifert, Chollet, &  
93    Mujika, 2011). For that reason, some authors have tried to find relationships between  
94    performance in multi-joint dry-land exercises involving the same muscle system required in  
95    swimming and swimming performance. Specifically, some of those studies have focused on  
96    strength-based dry-land variables as the repetition maximum test (RM) to predict swimming  
97    velocity (Crowe, Babington, Tanner, & Stager, 1999; Garrido et al., 2010; Johnson, Sharp, &  
98    Hedrick, 1993), meanwhile some others have observed the relationships between the velocity or  
99    power developed on those dry-land exercises with swimming performance (Dominguez-  
100    Castells, Izquierdo, & Arellano, 2013; Morouco et al., 2011; Perez-Olea, Valenzuela, Aponte, &  
101    Izquierdo, 2018; Ravé et al., 2018). However, in spite of the fact that force production capability  
102    is expected to be related to muscle strength and body mass, a key criticism is that testing  
103    performance in dry-land conditions may reduce testing effectiveness, as it could not replicate  
104    either the power requirements of real swimming nor the biomechanical aspects related to how  
105    the swimmer feels the water (Ravé, et al., 2018). The swimmer's performance does not only  
106    depend on the ability to produce large amounts of propulsive forces, but also on the ability to  
107    transfer and sustain such outputs to the water as the competition unfolds (dos Santos, Pereira,  
108    Papoti, Bento, & Rodacki, 2013). Hence, improving the ability to measure the force produced  
109    by the swimmers in the water could allow a real-time control of training and therefore optimize  
110    training potential.

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113    In-water resisted modalities as tethered or semi-tethered swimming have been proposed as a  
114    valid and reliable tool for the evaluation and control of training given their specificity and  
115    sensitivity on monitoring the similar muscular activity than in free swimming (Akis and Orcan,  
116    2004; N. Amaro, Marinho, Batalha, Marques, & Morouco, 2014; Morouco, Marinho, Keskinen,

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117 Badillo, & Marques, 2014). However, meanwhile some authors reported small or no limitations  
118 caused by tethered modalities (Morouço, Marinho, Izquierdo, Neiva, & Marques, 2015), some  
119 others reported critical kinematic changes that could lead to a different trajectory or acceleration  
120 of the hands compared with real swimming (Maglischo, Maglischo, Sharp, Zier, & Katz, 1984;  
121 Samson, Monnet, Bernard, Lacouture, & David, 2018). On the other hand, as the swimmers  
122 need to be attached through a taut cable from their waist to a cell fiber placed on a static point  
123 (normally the starting block), some authors have reported that tethered swimmers tend to kick  
124 considerably deeper during the trials because it produces a small angle in relation to water  
125 surface (N. Amaro, et al., 2014; Maglischo, et al., 1984). In addition, it may not only modify  
126 considerably the swimming patterns in low level swimmers or swimmers with no practical  
127 experience with these devices, but it may also produce an amount of small combined errors that  
128 should be taken into account by the researchers when reporting the results of their tethered  
129 measurements (Psycharakis, Paradisis, & Zacharogiannis, 2011). At last, although the forces  
130 gathered during a tethered swimming test represent the magnitude of the performed pull drive,  
131 and as such, this is a representation of the working potential that has to be realized during free  
132 swimming (Dopsaj et al., 2001; Morouco, et al., 2014; Psycharakis, et al., 2011), this method  
133 disregards the forces produced to overcome the drag that increases against the displacement of  
134 the swimmer (dos Santos, et al., 2013).

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136 For that reason, some authors have tried to solve the aforementioned issues by including a  
137 system capable to allow a displacement of the swimmer in the test trial (Dominguez-Castells  
138 and Arellano, 2012; Dominguez-Castells, et al., 2013; Hancock, Sparks, & Kullman, 2015;  
139 Johnson, et al., 1993; Klauck and Ungerechts, 1997). Klauck and Ungerechts (1997) used a  
140 semi-tethered swimming device to calculate the instantaneous mechanical power developed to  
141 external loads by registering the revolutions produced by the swimmer motion on a wheel.  
142 However, they only reported mean power values and the velocity fluctuations in every stroke  
143 were ignored. On the other hand, two studies (Dominguez-Castells and Arellano, 2012;  
144 Dominguez-Castells, et al., 2013), tested swimmers in a 12.5 m all-out front crawl swim across

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145 a pool connected to an underwater dumbbell by a rope. The velocity and power fluctuations  
146 delivered to the dumbbell were successfully calculated through a speedometer wire and a load  
147 cell connected to the swimmer; however, the swimmers were unable to sustain a stable  
148 swimming velocity and the swimming patterns were adversely affected. In addition, leg kicking  
149 was not allowed and it possibly increased body-roll, causing not only asymmetries on the force  
150 production, but also a low stability in the water (Mujika and Crowley, 2019; Psycharakis and  
151 Sanders, 2010). At last, semi-tethered swimming on adapted Power Racks through pulleys  
152 system (Hancock, et al., 2015; Johnson, et al., 1993; Ravé, et al., 2018), has been proposed as a  
153 valid and reliable tool because it allows not only to evaluate the power exerted in the water  
154 considering the balance between the resistive and propulsive forces originated by the  
155 displacement, but also to control the amount of weight lifted and the distance and time required  
156 to lift it. However, it is still intriguing to see if the swimmers' skills could be effectively  
157 improved through this method due to the possible alterations on the swimming kinetics and  
158 kinematics aforementioned reported.

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160 To author's knowledge, two variables such as the intra-cycle velocity variation ( $dv$ ) and intra-  
161 cycle force variation ( $dF$ ) may contain the key to understand the effectiveness of this method to  
162 apply high-resistance practices that do not influence the swimming skills adversely. These  
163 variables have been taken from tethered swimming as a way to evaluate the ability of the  
164 swimmers to effectively apply the propulsive forces in the water (Morouco, Barbosa, Arellano,  
165 & Vilas-Boas, 2017). Higher percentages of these variables would represent a high difference  
166 between the maximum and the minimum velocity/force values developed in every stroke as a  
167 consequence of a low-efficient application of the forces in the water. Therefore, it would lead in  
168 poorer performance because of a lower ability to sustain a stable swimming velocity. On the  
169 other hand, as every increase obtained in swimming velocity should be in line with an increase  
170 in the force and power production capability (Vorontsov, et al., 2011), it would be of interest for  
171 the athletic community an updated perspective of the relationships between the variables  
172 collected in dry-land conditions with actual swimming performance . Therefore, the purpose of



173 this study was: i) To present a protocol to assess swimming performance kinetics and  
174 kinematics in front crawl with different external loads; ii) to examine the  $dF$  and  $dv$  on a STLS  
175 test including a displacement; and iii) to study the relationships between the velocity of  
176 swimming achieved in every loaded effort and some variables collected by a dry-land exercise.

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## 178 MATERIAL AND METHODS

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### 180 EXPERIMENTAL APPROACH TO THE PROBLEM

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182 A quasi-experimental, cross-sectional design was used to explore performance in a STLS test.  
183 The study was conducted in two phases: In one session, every participant performed several  
184 STLS efforts with increasing loads. During a different session, the participants performed a  
185 repetition maximum strength test on a dry-land device simulating arm-stroke of swimming.  
186 Performance both in dry-land as in aquatic conditions were assessed from the kinetic/kinematic  
187 variables gathered through a linear encoder (Figure 1). Both tests were randomly applied to all  
188 the participants to avoid the “fatigue/learning” effect.

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190 In order to reduce the probability of Type I error, the differences in the STLS variables were  
191 observed within-subjects at 15, 30, 45 and 60% of the maximal load (ML). On the other hand,  
192 the relationships between the mean, maximum and minimum velocity achieved at every STLS  
193 effort and the strength- and velocity-based variables achieved in dry-land were studied by  
194 Pearson’s coefficient ( $r$ ). Additionally, this relationship was also explored with the velocity of  
195 swimming with no load, acting as a control.

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## 197 SUBJECTS

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3 199 Sixteen competitive male swimmers provided signed informed consent and volunteered to  
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5 200 participate in this study. The main physical and competitive background characteristics were  
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7 201 (mean  $\pm$  SD): 18.31  $\pm$  1.42 years old; 72.56  $\pm$  9.88 kg of body mass; 1.80  $\pm$  0.03 m of height;  
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9 202 76.28% performance level of the world record (50-m Freestyle, Short course), and  $\leq$  five years  
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11 203 of national level competitive participation. Swimmers under the age of 18 were asked to provide  
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13 204 written and signed parental consent.  
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20 206 The exclusion criteria included: i) no semi-tethered or in-water resisted practice during the last  
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22 207 three months; ii) unable to attend three sessions scheduled in this study; iii) suffering any injury  
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24 208 or disease in the past six months. All of the swimmers were reportedly free of the following:  
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26 209 drugs, medication, or dietary supplements known to influence physical performance. The tests  
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28 210 were scheduled to occur before their daily training regimen, and the subjects were instructed to  
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30 211 avoid any physical exertion before testing. All the procedures were performed in accordance  
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32 212 with the Declaration of Helsinki with respect to human research, and the study was approved by  
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34 213 the Institutional Review Board of the University with the number 852.  
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42 215 **PROCEDURES**  
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48 217 The participants conducted two incremental strength tests, both in dry-land and aquatic  
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50 218 conditions. An isoinertial dynamometer (T-Force Dynamic Measurement System, Ergotech,  
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52 219 Murcia, Spain), was used to acquire, display and process velocity-time data during the trials.  
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54 220 This system consists of a cable–extension linear velocity transducer interfaced to a personal  
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56 221 computer by means of a 14-bit resolution. Signal was acquired at a sampling rate of 1000 Hz.  
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58 222 The system was placed on the floor and was connected to the bar of an adapted Smith Machine  
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223 (Jim Sports Technology S.L., Lugo, Spain), positioned in the same place. To gather data from  
224 every maximal trial on the software application, a taut rope was attached through a home-made  
225 pulley system from the Smith Machine's bar to the swimmer's hands (Figure 1A) or hips  
226 (Figure 1B). Thus, every maximal effort automatically produced the lifting of the bar and  
227 therefore, a displacement registered by the encoder cable. All of the targeted loads were adapted  
228 considering the pulley system and previously confirmed with an electronic dynamometer  
229 (WeiHeng Electronics Co., Ltd., Guangzhou, China).

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231 On the first day, the participants performed a dry-land strength test designed according to the  
232 guidelines of the American College of Sports Medicine (Ferguson, 2014). It was performed on a  
233 Smith-Machine (Jim Sports Technology, S.L.) adapted with a home-made pulley system  
234 (Barton Marine Equipment Ltd., Whitstable, United Kingdom), which allowed the development  
235 of pulling actions away from the system as described by Cuenca-Fernandez, Ruiz-Teba, Lopez-  
236 Contreras, & Arellano (2018). The participants started the exercise in prone position on an  
237 inclined bench (45° from vertical) with both arms horizontally extended to the front and each  
238 hand holding a handle from the pulley system (Figure 1A). They were asked to perform a  
239 complete shoulder extension at maximal velocity, return to the starting position in a controlled  
240 manner, maintain the position for 0.5 seconds, and perform a second repetition. Every  
241 participant had to complete 2 repetitions with each load, increasing every 2 minutes. Through  
242 the linear encoder software, it was possible to obtain a prediction of the RM obtained from the  
243 first repetition. Therefore, the increments of the load were 10 kg at the beginning of the test and  
244 5 kg later (close to the maximal load).The test finished with the last load they could lift  
245 completely, and it was considered as the arm-stroke RM of the subjects ( $39.18 \pm 4.68$  kg). The  
246 relative load coefficient (Relative\_RM) was obtained by dividing the RM value achieved by  
247 each participant by their body weight. These two variables were considered as the strength-  
248 based dry-land variables. The additional velocity-based variables such as Mean propulsive

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249 velocity (MPV), Mean propulsive power (MPP) and Mechanic impulse (IMP), were directly  
250 provided by the encoder.

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252 On a second day, the participants moved on an experimental setting placed in a 25 m indoor  
253 pool (with water and air temperatures of 28.2 and 28.9° C, respectively). During this session, the  
254 swimming front crawl velocity with no load (NoLoadV) of the participants was collected. Each  
255 swimmer performed a 400m standardized warm-up consisting of 2x100m easy freestyle swim  
256 with 2 starts from the wall; 2x50m front crawl swim (12'5 fast; 12'5 smooth) and 100m front  
257 crawl at a normal pace followed by a dynamic stretching protocol both for the upper and the  
258 lower limbs as described by Cuenca-Fernandez, et al. (2018). Subsequently, they were tested on  
259 an in-water 25m all out swimming effort. One digital video camera (Sony Video Camera, 50Hz;  
260 Sony Electronics Inc., Tokyo, Japan), was installed on an underwater window at the poolside.  
261 This camera recorded the phase from 5 to 10 m. After the test, the velocity values were obtained  
262 from the underwater video files in Kinovea (Kinovea, version 0.7.10, France), as the distance  
263 from 5 to 10 m divided by the time elapsed during such action ( $1.75 \pm 0.08$  m/s). After that, the  
264 swimmers were given a first experience of two efforts in the semi-tethered device.

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266 During a third session, the participants performed the same warm-up protocol and after 6 min of  
267 rest, they started the first trial of the STLS. The loads of the STLS were applied on the bar of an  
268 adapted Smith Machine connected to the swimmer's hip through a taut rope (Figure 1B). An in-  
269 water start was used and swimmers were instructed to reduce gliding. Although a previous study  
270 suggested that breathing patterns seem to not influence symmetry or performance in tethered  
271 swimming (N. M. Amaro, Morouço, Marques, Fernandes, & Marinho, 2017), the participants of  
272 this study were instructed to hold their breath during the effort in order to avoid any possible  
273 influence of this action on the encoder recordings. The test started with 1 kg of load (after the  
274 pulley system), and it was increased by successive 1 kg increments. Every trial ended when the

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275 swimmers reached the maximal extension of the rope (15 m) and all the efforts had time  
276 duration of between 10 to 20 seconds. Six minutes of rest were given between trials (Hancock,  
277 et al., 2015). As every swimming effort produced the lift of the bar, it allowed to obtain through  
278 the encoder the velocity of swimming regarding the load added to the bar. The test finished  
279 when the lift of the bar produced swimming velocities under 0.65-0.55 m/s, as previous research  
280 recommended it avoidable (Dominguez-Castells and Arellano, 2012). The percentage of load  
281 pulled was estimated for every participant as the percentage of velocity loss regarding the  
282 velocity achieved with no load (Gonzalez-Badillo and Sanchez-Medina, 2010). Under this basis,  
283 the power/velocity vs. load curves were calculated at 15, 30, 45 and 60% ML. To avoid any  
284 effect of the impulse of the swimmer from the wall and the force asymmetries expected on the  
285 first cycles of the maximal swimming efforts (Morouço, Marinho, Fernandes, & Marques,  
286 2015), the first 4 arm-strokes were excluded and the 10 consecutive arm-stroke cycles were  
287 selected for further analysis.

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289 (Please insert Figure 1 near here)

290

291 **VARIABLES MEASURED**

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293 Average instantaneous velocity and acceleration were acquired from the encoder at a sampling  
294 rate of 1000Hz. Velocity and acceleration-time curves were smoothed using a fourth order  
295 Butterworth low pass digital filter, with a cut off frequency of 10 Hz, defined according to  
296 residual analysis (residual error versus cut-off frequency). The variations on the acceleration  
297 curves with respect to time were used to identify the arm-strokes performed by the swimmer.  
298 Every curve registered on the acceleration values above zero was considered as a one arm  
299 stroke. The maximal and minimum values of velocity were calculated as means  $\pm$  SD from

300 every arm stroke, obtained directly through the encoder used in 10 consecutive arm stroke  
301 cycles ( $m \cdot s^{-1}$ ). The distance covered in 10 strokes (DC10St) was directly calculated as the time  
302 to complete 10 strokes (T10St) multiplied by the velocity achieved.

303

304 The force delivered to the load was calculated according to Newton's second law (Equation 1),  
305 where  $m$  stands for the load lifted on the Smith Machine in each situation and  $a$  stands for the  
306 instantaneous variations on the acceleration registered by the encoder in the Smith Machine's  
307 bar while lifting. The swimming power delivered to the load (average/peak) was calculated as  
308 the force (average/peak) multiplied by the velocity delivered (average/peak).

309

$$310 \quad F = m \cdot a \quad \text{Equation 1}$$

311

312 The impulse was calculated as the mean  $\pm$  SD of the values obtained in every single arm stroke  
313 according to the equation 2. Where  $s$  stands for the beginning of the stroke (instant of the force  
314 change),  $e$  for the end of the stroke and  $F$  stands for the force;  $\Delta t$  was 1/1000 (frequency of data  
315 acquisition: 1000 Hz). The impulse normalized to the weight pulled (ImpRel) was obtained by  
316 dividing the absolute values of impulse by the mass of the load pulled (in kg).

317

$$318 \quad \sum_s^e F \cdot \Delta t \quad \text{Equation 2}$$

319

320 The intra-cyclic variation of the horizontal velocity of the hip ( $dv$ ) and the intra-cyclic variation  
321 of the horizontal force exerted by the swimmer to the load pulled ( $dF$ ), was analyzed as  
322 previously described by Morouco, et al. (2017), (Equation 3). Where  $x$  represents either the  
323 mean swimming velocity or force,  $x_i$  represents either the instantaneous swimming velocity or

324 force,  $F_i$  represents the acquisition frequency 1/1000 (frequency of data acquisition: 1000 Hz),  
325 and  $n$  is the number of measured strokes.

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327 
$$dv \ \& \ dF = \frac{\sqrt{\sum i(x_i - \bar{x})^2 \cdot F_i}}{\frac{\sum i x_i \cdot F_i}{n}} \cdot 100 \quad \text{Equation 3}$$

328

### 329 **STATISTICAL ANALYSES**

330

331 Descriptive statistics were obtained and the data was expressed as mean  $\pm$  SD, confidence  
332 intervals (CIs) (95%). The test-retest reliability (intraclass correlation coefficient [ICC]), within  
333 and between observers was analyzed for the  $dv$ . Five trials (5 digitized by the researcher, and the  
334 other 5 digitized by other researchers with experience in the processing computational routine),  
335 were conducted on 10 swimmers who completed 4 trials with different loads. The intraobserver  
336 ICC ranged between 0.95 (95% CI, 0.92 – 0.99) and 0.96 (95%, 0.92-0.98), and the  
337 interobserver ICC ranged from 0.97 (95% CI, 0.96 – 0.98) to 0.99 (95% CI, 0.98 – 0.99) for the  
338 tethered measurements.

339

340 The effect sizes ( $d$ ) of the obtained differences were calculated and categorized (small if  $0 \leq |d|$   
341  $\leq 0.5$ , medium if  $0.5 < |d| \leq 0.8$ , and large if  $|d| > 0.8$  (Cohen, 1988). After Shapiro-Wilk testing  
342 for normality distribution, repeated measures 1-way ANOVA tests were carried out to find  
343 differences between the variables at 15, 30, 45 and 60% of the maximal load (ML). To detect  
344 differences between variables, significance was accepted at the  $\alpha \leq 0.05$  level, and paired  
345 comparisons were used in conjunction with Holm's Bonferroni method for controlling type 1  
346 errors.

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3 348 Pearson product-moment correlation coefficients ( $r$ ) were used to verify the relationship  
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5 349 between the swimming velocities and the different sorts of strength-based and velocity-based  
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7 350 variables obtained on the dry-land arm-stroke strength test. All statistical procedures were  
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9 351 performed using SPSS 21.0 (IBM Chicago, IL, USA).

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16 353 **RESULTS**

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22 355 Mean, SD,  $P$  – values and Effect sizes for all tested STLS variables are presented in Table 1.  
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24 356 Most of the variables were adversely affected by the load pulled. The velocity of swimming was  
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26 357 different ( $F_{3,13} = 977.72$ ,  $p = 0.000$ ) and decreased along with the load pulled. In addition, the  
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28 358 time to complete the ten arm-strokes ( $F_{3,13} = 12.616$ ,  $p = 0.000$ ) and the distance covered ( $F_{3,13} =$   
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30 359  $307.22$ ,  $p = 0.000$ ) was also affected because both variables were progressively lower when  
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32 360 increasing the load. The power values were different depending on the load (Mean:  $F_{3,13} =$   
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34 361  $20.345$ ,  $p = 0.000$ ; Peak:  $F_{3,13} = 27.158$ ,  $p = 0.000$ ). The highest mean values were obtained at  
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36 362 45% ML (Power:  $57.50 \pm 10.94$  W) (Figure 2), meanwhile the peaks were both found at some  
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38 363 point between 30 and 45% ML. From that point onwards, the power values decreased (Table 1).

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46 365 The values of Force, Acceleration, Impulse and ImpRel were different in every effort ( $p <$   
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48 366  $0.05$ ). The highest values of force and impulse were obtained at 60% ML, while the highest  
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50 367 values of Acceleration and ImpRel were acquired at 15% ML (Table 1). The  $dv$  values were  
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52 368 different ( $F_{3,17} = 12.142$ ,  $P = 0.000$ ), although *post-hoc* only revealed a significant increase at  
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54 369 60% ML ( $p < 0.002$ ) in comparison with the rest of the efforts. Finally, no differences were  
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56 370 detected in  $dF$  as a consequence of increasing the load ( $F_{3,13} = 1.851$ ,  $P = 0.188$ ).

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372 (Please insert Table 1 near here)

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374 (Please insert Figure 2 near here)

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376 The correlations between the velocity of swimming and the variables collected in dry-land  
377 conditions through the Smith Machine's device are shown in Table 2. Pearson's correlation  
378 coefficient detected a moderate to strong relationship between the RM and the Relative\_RM of  
379 the swimmers and the mean velocity with no load ( $r = 0.496, p = 0.050$ ;  $r = 0.529, p = 0.035$ ;  
380 respectively). Regarding the velocity achieved in the different STLS efforts, the RM only  
381 correlated with some swimming velocities manifestations at 60% ML, meanwhile the  
382 Relative\_RM achieved some correlations at 15 and 30% ML (Table 2). On the other hand, MPV  
383 and MPP reached strong and moderate correlations with the mean swimming velocity with no  
384 load ( $r = 0.709, p = 0.002$ ;  $r = 0.564, p = 0.023$ ; respectively). Furthermore, some other  
385 correlations were found between these variables with the maximum and minimum velocities  
386 achieved in the different STLS efforts (Table 2). The higher the velocity and power applied on  
387 the dry-land test, the higher the velocity of swimming, even at different loads. Finally, the IMP  
388 acquired on the arm-stroke dry-land exercise, reached a negative correlation with the velocity of  
389 swimming with no load ( $r = -0.554, p = 0.026$ ) and some of the STLS efforts (Table 2). In this  
390 sense, high values of impulse in the dry-land exercise were associated with lower velocities of  
391 real swimming, especially with the maximum velocities achieved at 30, 45 and 60% ML ( $p <$   
392  $0.03$ ).

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394 (Please insert Table 2 near here)

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396 **DISCUSSION**

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3 398 One of the purposes of our study was to present an updated protocol to assess semi-tethered  
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5 399 swimming performance in front crawl. The power vs. load curves presented an inverted ‘U’  
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7 400 shape (Figure 1), similar to those obtained by previous authors (Dominguez-Castells, et al.,  
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9 401 2013; Garcia-Ramos et al., 2016). Nevertheless, although the peak power output was achieved  
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11 402 at some point between the 30% ML ( $67.21 \pm 10.79$  W) and 45% ML ( $71.38 \pm 10.12$  W) ( $p =$   
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13 403  $0.137$ ), the higher value of mean power was found at 45% ML (Figure 1), and it corresponded  
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15 404 to a swimming velocity of  $0.95 \pm 0.06$  m/s. Those values were very similar to the ones obtained  
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17 405 by Dominguez-Castells, et al. (2013) ( $66.49 \pm 19.09$  W), although they reported lower velocity  
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19 406 values ( $0.75 \pm 0.18$  m/s). In addition, those results were achieved at a very similar load  
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21 407 percentage (47% ML:  $3.95 \pm 0.79$  kg), although in the present study, that load percentage  
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23 408 corresponded to a larger load mass (45% ML:  $6.00 \pm 0.98$  kg). The reasons to discuss it are two-  
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25 409 fold; At first, it is important to consider that leg kicking was not restricted in our study and it  
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27 410 obviously provides significant propulsion (Deschodt, Arsac, & Rouard, 1999; Morouço,  
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29 411 Marinho, Izquierdo, et al., 2015). Moreover, it has been noted that leg kicking has a  
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31 412 considerable influence on body-roll because it applies a torque on the hip that limits the hip  
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33 413 rotation (Sanders and Psycharakis, 2009). Therefore, it may provide a higher stabilization in the  
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35 414 development of the swimming movements (Psycharakis and Sanders, 2010). On the other hand,  
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37 415 the resistance offered by the added mass may be higher underwater given the quadratic nature of  
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39 416 the hydrodynamic drag (Marinho et al., 2009). In such case, the external work was higher not  
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41 417 only because of the increases of the load, but also because of the drag offered by the dumbbell  
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43 418 when accelerating (Dominguez-Castells, et al., 2013; Hollander et al., 1986).

419

420 By contrast, in the study of Johnson, et al. (1993), the resistance of the added mass was applied  
421 externally on a power rack, and the values were collected without inhibiting the leg actions.  
422 Such a method was more akin to what was applied in this study, however, the peak power

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423 output was slightly higher than the maximal values achieved in this study ( $80 \pm 21$  W vs.  $71.38$   
424  $\pm 10.12$  W) and the load eliciting that peak power was significantly superior (7.8 kg) than the  
425 range of loads found in our study (4.37 – 6.00 kg). Possibly, since Power was calculated in both  
426 studies as (Force · Distance) / Time, the differences would come from the procedure to obtain  
427 the Force value. In the study of Johnson, et al. (1993), it was calculated solely as the weight  
428 pulled by the swimmers, meanwhile in the present study, the Force values were determined  
429 according to Newton's second law ( $F = m \cdot a$ ). Therefore, the values achieved at high loads  
430 might have been countered by the low acceleration achieved (Table 1), and therefore, this may  
431 have influenced the outcomes obtained in Power.

432

433 Furthermore, according to the force-velocity relationship of the skeletal muscle, the outcomes  
434 obtained in Force and Impulse could be expected (Table 1), indicating that at very high velocity  
435 contractions, it is not easy to accumulate high amounts of force and impulse values and once the  
436 resistance loads grow, the force and impulse needed to overcome them increases (Dopsaj, et al.,  
437 2001; Garcia-Ramos, et al., 2016; Keskinen, Tilli, & Komi, 1989). Considering that any  
438 increase in swimming velocity requires a proportional increase in the applied muscle force to  
439 sustain such velocity (Vorontsov, et al., 2011), this fact may reflect an augmented quantity of  
440 the propulsive movements conveyed per stroke at high loads, a key that might be of success for  
441 sprinters (N. Amaro, et al., 2014; Dopsaj, et al., 2001). However, the loss of velocity and  
442 acceleration, together with the reduction of the distance covered and the time in the 10 arm-  
443 strokes were not in line with the increases obtained in force and absolute impulse at high loads  
444 but in line with the reduction of the Impulse normalized to the load pulled (ImpRel). Therefore,  
445 if STLS does not produce any increase on the propulsive skills, but deterioration on them, it  
446 should be highly reconsidered when including in-water resisted swimming routines, as little or  
447 no benefit may be obtained from them.

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449 In any case, coaches should be aware that the application of different loads in STLS may affect  
450 the subjects' performance differently. Lower power production at fast velocities and low loads  
451 might indicate a high resistive drag and a low swimming efficiency, meanwhile a low power  
452 production at heavy loads and low velocities might indicate deficits in the swimmers strength  
453 (Dopsaj, et al., 2001; Johnson, et al., 1993). For that reason, another aim of this study was to  
454 examine the intra-cycle velocity ( $dv$ ) and force variation ( $dF$ ) along with the increasing loads.  
455 The  $dv\%$  and  $dF\%$  represents a balance between propulsive and resistive forces. The higher the  
456  $dv\%$  and  $dF\%$  the poorer the performance, as it represents a low-efficient application of the  
457 forces in the water (Barbosa et al., 2013). In our study, the highest  $dv\%$  was obtained at the  
458 highest load and lowest velocity. In fact, the deepest variation in  $dv\%$  was detected between 45  
459 to 60% ML ( $p < 0.001$ ), coinciding also with the loss of swimming power (Table 1). These  
460 results were expected. Sustaining high swim velocities is obviously hard while pulling heavy  
461 loads because the swimmer is unable to find the impulse needed to overcome the resistance in  
462 an unstable environment such as water. It implies increases in power and strength requirements  
463 of the muscles (e.g. with speed), which require stiffer tendons to produce optimal efficiency and  
464 the required power with a given muscle volume. The greater force generated by muscle is  
465 associated with the transmission of more stress through the tendon. Consequently, higher  
466 muscle requirements also produce higher fatigue and it may affect the swimming technique  
467 adversely (Cuenca-Fernandez, et al., 2018).

468  
469 Morouco, et al. (2017) reported that swimmers with higher  $dv\%$  would also present higher  $dF\%$ .  
470 However, the  $dF\%$  did not change along with the increase of the load (Figure 2), and actually, it  
471 seemed to be slightly reduced as a consequence of it. Possibly, as the time to complete the 10  
472 arm-strokes was shorter at higher loads, it indicated that every arm-stroke was not only shorter,  
473 but also produced less propulsive impulse. This modification on the stroke patterns may be a  
474 consequence of the increased difficulty to transfer the force into the water at maximal or sub-  
475 maximal loads and would also be consistent with the results found in the present study for

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476 ImpRel (Table 1). Nevertheless, previous studies have shown that semi-tethered swimmers may  
477 increase the coordination index by overlapping the arm strokes, and this effect may reduce the  
478 dF% (Dominguez-Castells and Arellano, 2012; Schnitzlerl, Seifert, Ernwein, & Chollet, 2008;  
479 Seifert, Chollet, & Bardy, 2004). Unfortunately, that variable was not measured in this study  
480 and future research should provide more information about this issue, testing also if swimmers  
481 with a high dF% may benefit from STLS practice to reduce it.

482  
483 The associations found between the dry-land variables and the velocity of swimming (Table 2),  
484 are not new as previous studies have shown considerable interest in this field (Crowe, et al.,  
485 1999; Dominguez-Castells, et al., 2013; Garrido, et al., 2010; Perez-Olea, et al., 2018; Ravé, et  
486 al., 2018). In the study of Johnson, et al. (1993), the RM achieved on the *bench press* exercise  
487 was correlated with the swimming velocity ( $r = 0.55$ ), meanwhile in the study of Garrido, et al.  
488 (2010), a similar correlation was found ( $r = 0.58$ ) compared with the load at 6RM. However,  
489 both authors pointed out that the nature of the selected exercise was possibly not specific  
490 enough to expect that improvements in strength would result in improved swimming  
491 performance. In contrast, Crowe, et al. (1999), obtained higher correlations ( $r = 0.65$ ), between  
492 the RM obtained in *lat pull-down* (i.e. in a pulling exercise) and swimming performance  
493 measured in 50 meters. For that reason, despite RM being more related with maximum force  
494 than with explosive force, the associations between swimming velocity with the RM ( $r = 0.49$ )  
495 and Relative\_RM ( $r = 0.52$ ) were explored in this study through a pulling exercise, which would  
496 support the development of muscular strength in swimmers, as it appears to play an important  
497 role in the determination of maximal swim velocity.

498  
499 Nevertheless, it is worthy of review that while the RM only showed moderate to strong  
500 correlations with V60 ( $r = 0.68$ ) and Vmin60 ( $r = 0.52$ ) (i.e. at higher loads), the Relative\_RM,  
501 reached correlations with V15 ( $r = 0.52$ ), Vmin15 ( $r = 0.52$ ) and V30 ( $r = 0.54$ ) (i.e. at lower  
502 loads). Since the fact that producing a high percentage of Relative\_RM is the greater capacity of

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503 force due to lower body weight, the Relative\_RM index may reflect with more accuracy the  
504 strength abilities of the swimmers (Cuenca-Fernández et al., 2015). Possibly, considering that  
505 higher swimming velocities were achieved at low loads (Table 1), the correlation with the  
506 Relative\_RM index may also reflect that those swimmers presented a lower surface area and  
507 hydrodynamic drag than the average (Hollander, et al., 1986). At 60% ML, under a severe  
508 reduction of swimming velocity ( $p < 0.000$ ) and consequently in the drag acting against the  
509 body (Marinho, et al., 2009), the RM of the swimmers was shown as a predictor to achieve and  
510 maintain a higher swimming velocity (Table 2). It may indicate that regardless of their strength  
511 abilities, the swimmers with a high value of Relative\_RM may presumably offer less drag than  
512 the average and it would be more reliable than testing only the RM to predict real swimming  
513 performance. Moreover, it would offer a valid and different rationale arguing why studies  
514 testing performance in tethered swimming (i.e. with no drag acting against the body) have  
515 shown to be more related with the absolute force values rather than with the relative ones  
516 (normalized to body mass) (Morouco, et al., 2011).

517  
518 On the other hand, as movement velocity has shown to be a predictor of loading intensity and  
519 strength capability in resistance training (Gonzalez-Badillo and Sanchez-Medina, 2010),  
520 different velocity-based perspectives have been carried out to link performance obtained in dry-  
521 land conditions with actual swimming. Morouco, et al. (2011), found correlations ( $r = 0.68$ )  
522 between MPP in *lat pull down* and velocity of swimming in 50m. Meanwhile, in the study of  
523 Dominguez-Castells, et al. (2013) the maximum power obtained on a dry-land arm-stroke  
524 exercise, was relatively similar to maximum swim power ( $r = 0.91$ ), and both of these power  
525 values were related to swim velocity ( $r = 0.85$ ,  $r = 0.72$ ). On the other hand, Perez-Olea, et al.  
526 (2018) recently demonstrated that the mean velocity reached in a test of maximal number of  
527 *pull-ups* correlated with swimming velocity ( $r = 0.88$ ), and the relative loss of velocity during  
528 the pull-up test accounted for 84% ( $p < 0.001$ ) of 50m freestyle performance variance. Thus,  
529 those results were in agreement with the ones obtained in this study as two of the velocity-based  
530 variables, MPV and MPP, correlated with different velocities achieved at different STLS efforts

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531 (Table 2). Meanwhile, the negative correlation obtained between IMP and swimming velocity  
532 indicated that for a given force in N, the lower the velocity of the arm-stroke, the higher the time  
533 spent to complete the movement. Therefore, considering that swimming is characterized by  
534 producing fast movements in a short period of time, especially when sprinting (Seifert, et al.,  
535 2004), velocity-based dry-land variables may constitute an effective approach to predict actual  
536 swimming performance.

537  
538 The results of the present investigation have shown that STLS alters the swimming kinetics and  
539 kinematics. A reduction of the time spent per stroke is obtained due to loaded swimming and it  
540 seems not possible to achieve the higher requirements of force/impulse needed to overcome the  
541 high loads. Those alterations seem to be higher from 45% ML onwards, with greater increases  
542 in critical variables as  $dv\%$  which indicated a high difficulty to maintain a constant speed in the  
543 water and a deep deterioration in performance. Therefore, STLS should be cautiously  
544 administered to include specific high-intensity force development programs, since its transfer to  
545 improve the biomechanical skills of the swimmers seems questionable. Regarding the results  
546 obtained in the dry-land test, the swimmers with higher index of relative strength may obtain  
547 better results in STLS at low loads and higher speed, although the ability to develop a high  
548 amount of absolute strength seems relevant for swimmers. Possibly, as the velocity obtained  
549 when pulling a low resistance in the STLS likely reflects the combined contribution of the  
550 propulsive skills and minimized body drag, the improvement in either of these components  
551 could result in improved swimming performance scores. In any case, swimming performances  
552 seem to be better predicted through dry-land exercises which allow the development of high  
553 speed and explosive movements, possibly because actual swimming movements are produced  
554 quickly and intensely in a short period of time.

555  
556 This study presented some limitations, as the correlations presented here were obtained  
557 according to swimmers' upper limb strength; however, the semi-tethered encoder recordings  
558 might not just be from the arm action throughout the underwater stroke, but also from the leg

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559 action. On the other hand, although participants had one previous practice with the STLS  
560 device, it was possible not enough to get familiarized enough with it. Nevertheless, a simple  
561 adaptation of a system used to measure performance in dry-land conditions allowed us to  
562 measure performance in swimmers. Moreover, this system has shown to be sensitive in  
563 obtaining valuable information about intra-cyclic velocity or force variation, which could lead  
564 coaches to focus on improving swimmer's technique rather than increasing physical  
565 conditioning.

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568

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572 development of International Swimmers in Short Swimming Events (50 and 100M)].

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## 574 **DECLARATION OF INTEREST STATEMENT**

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576 No potential conflict of interest was reported by the authors.

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1 **The effect of different loads on semi-tethered swimming and its relationship with dry-land**  
2 **performance variables.**

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21 **ABSTRACT**

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23 Semi-tethered loaded swimming (denoted STLS) has been used widely to develop or test  
24 swimmers skills, although its transference to increase performance seems overestimated. In  
25 addition, its relationship with dry-land tests remains obscured by imprecise reports. Sixteen  
26 competitive male swimmers (age:  $18.31 \pm 1.42$ ) participated in a two-fold purpose study:  
27 Firstly, swimming performance was assessed at different STLS intensities on an adapted Smith  
28 Machine. A repeated measures 1-way ANOVA was conducted to find differences between the  
29 variables collected through a linear encoder at 15, 30, 45 and 60% of the maximal load (ML).  
30 Secondly, the relationships between the swimming velocities and the different sorts of variables  
31 obtained on a dry-land arm-stroke strength test were studied by Pearson's correlation coefficient  
32 ( $r$ ). The results showed that less velocity, acceleration and impulse were delivered at high loads  
33 ( $p < 0.001$ ). It increased the velocity fluctuation, affecting the swimming patterns adversely. On  
34 the other hand, the correlations between velocity-based dry-land variables and swimming  
35 velocities ( $r = 0.71$ ) seem to be more suitable to predict swimming performance, rather than  
36 strength-based variables ( $r = 0.49$ ). In conclusion, coaches should reconsider using STLS, as  
37 little or no benefit may be obtained in performance.

38

39 **KEY WORDS:** Swimming power; Performance assessment; Strength; Dry-land

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45 **INTRODUCTION**

46

47 The development of strength is crucial in swimming competition (Vorontsov, Seifert, Chollet, &  
48 Mujika, 2011). For that reason, some authors have tried to find relationships between  
49 performance in multi-joint dry-land exercises involving the same muscle system required in  
50 swimming and swimming performance. Specifically, some of those studies have focused on  
51 strength-based dry-land variables as the repetition maximum test (RM) to predict swimming  
52 velocity (Crowe, Babington, Tanner, & Stager, 1999; Garrido et al., 2010; Johnson, Sharp, &  
53 Hedrick, 1993), meanwhile some others have observed the relationships between the velocity or  
54 power developed on those dry-land exercises with swimming performance (Dominguez-  
55 Castells, Izquierdo, & Arellano, 2013; Morouco et al., 2011; Perez-Olea, Valenzuela, Aponte, &  
56 Izquierdo, 2018; Ravé et al., 2018). However, in spite of the fact that force production capability  
57 is expected to be related to muscle strength and body mass, a key criticism is that testing  
58 performance in dry-land conditions may reduce testing effectiveness, as it could not replicate  
59 either the power requirements of real swimming nor the biomechanical aspects related to how  
60 the swimmer feels the water (Ravé, et al., 2018). The swimmer's performance does not only  
61 depend on the ability to produce large amounts of propulsive forces, but also on the ability to  
62 transfer and sustain such outputs to the water as the competition unfolds (dos Santos, Pereira,  
63 Papoti, Bento, & Rodacki, 2013). Hence, improving the ability to measure the force produced  
64 by the swimmers in the water could allow a real-time control of training and therefore optimize  
65 training potential.

66

67

68 In-water resisted modalities as tethered or semi-tethered swimming have been proposed as a  
69 valid and reliable tool for the evaluation and control of training given their specificity and  
70 sensitivity on monitoring the similar muscular activity than in free swimming (Akis and Orcan,  
71 2004; N. Amaro, Marinho, Batalha, Marques, & Morouco, 2014; Morouco, Marinho, Keskinen,

72 Badillo, & Marques, 2014). However, meanwhile some authors reported small or no limitations  
73 caused by tethered modalities (Morouço, Marinho, Izquierdo, Neiva, & Marques, 2015), some  
74 others reported critical kinematic changes that could lead to a different trajectory or acceleration  
75 of the hands compared with real swimming (Maglischo, Maglischo, Sharp, Zier, & Katz, 1984;  
76 Samson, Monnet, Bernard, Lacouture, & David, 2018). On the other hand, as the swimmers  
77 need to be attached through a taut cable from their waist to a cell fiber placed on a static point  
78 (normally the starting block), some authors have reported that tethered swimmers tend to kick  
79 considerably deeper during the trials because it produces a small angle in relation to water  
80 surface (N. Amaro, et al., 2014; Maglischo, et al., 1984). In addition, it may not only modify  
81 considerably the swimming patterns in low level swimmers or swimmers with no practical  
82 experience with these devices, but it may also produce an amount of small combined errors that  
83 should be taken into account by the researchers when reporting the results of their tethered  
84 measurements (Psycharakis, Paradisis, & Zacharogiannis, 2011). At last, although the forces  
85 gathered during a tethered swimming test represent the magnitude of the performed pull drive,  
86 and as such, this is a representation of the working potential that has to be realized during free  
87 swimming (Dopsaj et al., 2001; Morouco, et al., 2014; Psycharakis, et al., 2011), this method  
88 disregards the forces produced to overcome the drag that increases against the displacement of  
89 the swimmer (dos Santos, et al., 2013).

90

91 For that reason, some authors have tried to solve the aforementioned issues by including a  
92 system capable to allow a displacement of the swimmer in the test trial (Dominguez-Castells  
93 and Arellano, 2012; Dominguez-Castells, et al., 2013; Hancock, Sparks, & Kullman, 2015;  
94 Johnson, et al., 1993; Klauck and Ungerechts, 1997). Klauck and Ungerechts (1997) used a  
95 semi-tethered swimming device to calculate the instantaneous mechanical power developed to  
96 external loads by registering the revolutions produced by the swimmer motion on a wheel.  
97 However, they only reported mean power values and the velocity fluctuations in every stroke  
98 were ignored. On the other hand, two studies (Dominguez-Castells and Arellano, 2012;  
99 Dominguez-Castells, et al., 2013), tested swimmers in a 12.5 m all-out front crawl swim across

100 a pool connected to an underwater dumbbell by a rope. The velocity and power fluctuations  
101 delivered to the dumbbell were successfully calculated through a speedometer wire and a load  
102 cell connected to the swimmer; however, the swimmers were unable to sustain a stable  
103 swimming velocity and the swimming patterns were adversely affected. In addition, leg kicking  
104 was not allowed and it possibly increased body-roll, causing not only asymmetries on the force  
105 production, but also a low stability in the water (Mujika and Crowley, 2019; Psycharakis and  
106 Sanders, 2010). At last, semi-tethered swimming on adapted Power Racks through pulleys  
107 system (Hancock, et al., 2015; Johnson, et al., 1993; Ravé, et al., 2018), has been proposed as a  
108 valid and reliable tool because it allows not only to evaluate the power exerted in the water  
109 considering the balance between the resistive and propulsive forces originated by the  
110 displacement, but also to control the amount of weight lifted and the distance and time required  
111 to lift it. However, it is still intriguing to see if the swimmers' skills could be effectively  
112 improved through this method due to the possible alterations on the swimming kinetics and  
113 kinematics aforementioned reported.

114

115 To author's knowledge, two variables such as the intra-cycle velocity variation ( $dv$ ) and intra-  
116 cycle force variation ( $dF$ ) may contain the key to understand the effectiveness of this method to  
117 apply high-resistance practices that do not influence the swimming skills adversely. These  
118 variables have been taken from tethered swimming as a way to evaluate the ability of the  
119 swimmers to effectively apply the propulsive forces in the water (Morouco, Barbosa, Arellano,  
120 & Vilas-Boas, 2017). Higher percentages of these variables would represent a high difference  
121 between the maximum and the minimum velocity/force values developed in every stroke as a  
122 consequence of a low-efficient application of the forces in the water. Therefore, it would lead in  
123 poorer performance because of a lower ability to sustain a stable swimming velocity. On the  
124 other hand, as every increase obtained in swimming velocity should be in line with an increase  
125 in the force and power production capability (Vorontsov, et al., 2011), it would be of interest for  
126 the athletic community an updated perspective of the relationships between the variables  
127 collected in dry-land conditions with actual swimming performance . Therefore, the purpose of

128 this study was: i) To present a protocol to assess swimming performance kinetics and  
129 kinematics in front crawl with different external loads; ii) to examine the  $dF$  and  $dv$  on a STLS  
130 test including a displacement; and iii) to study the relationships between the velocity of  
131 swimming achieved in every loaded effort and some variables collected by a dry-land exercise.

132

## 133 MATERIAL AND METHODS

134

### 135 EXPERIMENTAL APPROACH TO THE PROBLEM

136

137 A quasi-experimental, cross-sectional design was used to explore performance in a STLS test.  
138 The study was conducted in two phases: In one session, every participant performed several  
139 STLS efforts with increasing loads. During a different session, the participants performed a  
140 repetition maximum strength test on a dry-land device simulating arm-stroke of swimming.  
141 Performance both in dry-land as in aquatic conditions were assessed from the kinetic/kinematic  
142 variables gathered through a linear encoder (Figure 1). Both tests were randomly applied to all  
143 the participants to avoid the “fatigue/learning” effect.

144

145 In order to reduce the probability of Type I error, the differences in the STLS variables were  
146 observed within-subjects at 15, 30, 45 and 60% of the maximal load (ML). On the other hand,  
147 the relationships between the mean, maximum and minimum velocity achieved at every STLS  
148 effort and the strength- and velocity-based variables achieved in dry-land were studied by  
149 Pearson’s coefficient ( $r$ ). Additionally, this relationship was also explored with the velocity of  
150 swimming with no load, acting as a control.

151

## 152 SUBJECTS

153

154 Sixteen competitive male swimmers provided signed informed consent and volunteered to  
155 participate in this study. The main physical and competitive background characteristics were  
156 (mean  $\pm$  SD): 18.31  $\pm$  1.42 years old; 72.56  $\pm$  9.88 kg of body mass; 1.80  $\pm$  0.03 m of height;  
157 76.28% performance level of the world record (50-m Freestyle, Short course), and  $\leq$  five years  
158 of national level competitive participation. Swimmers under the age of 18 were asked to provide  
159 written and signed parental consent.

160

161 The exclusion criteria included: i) no semi-tethered or in-water resisted practice during the last  
162 three months; ii) unable to attend three sessions scheduled in this study; iii) suffering any injury  
163 or disease in the past six months. All of the swimmers were reportedly free of the following:  
164 drugs, medication, or dietary supplements known to influence physical performance. The tests  
165 were scheduled to occur before their daily training regimen, and the subjects were instructed to  
166 avoid any physical exertion before testing. All the procedures were performed in accordance  
167 with the Declaration of Helsinki with respect to human research, and the study was approved by  
168 the Institutional Review Board of the University with the number 852.

169

## 170 **PROCEDURES**

171

172 The participants conducted two incremental strength tests, both in dry-land and aquatic  
173 conditions. An isoinertial dynamometer (T-Force Dynamic Measurement System, Ergotech,  
174 Murcia, Spain), was used to acquire, display and process velocity-time data during the trials.  
175 This system consists of a cable–extension linear velocity transducer interfaced to a personal  
176 computer by means of a 14-bit resolution. Signal was acquired at a sampling rate of 1000 Hz.  
177 The system was placed on the floor and was connected to the bar of an adapted Smith Machine

178 (Jim Sports Technology S.L., Lugo, Spain), positioned in the same place. To gather data from  
179 every maximal trial on the software application, a taut rope was attached through a home-made  
180 pulley system from the Smith Machine's bar to the swimmer's hands (Figure 1A) or hips  
181 (Figure 1B). Thus, every maximal effort automatically produced the lifting of the bar and  
182 therefore, a displacement registered by the encoder cable. All of the targeted loads were adapted  
183 considering the pulley system and previously confirmed with an electronic dynamometer  
184 (WeiHeng Electronics Co., Ltd., Guangzhou, China).

185

186 On the first day, the participants performed a dry-land strength test designed according to the  
187 guidelines of the American College of Sports Medicine (Ferguson, 2014). It was performed on a  
188 Smith-Machine (Jim Sports Technology, S.L.) adapted with a home-made pulley system  
189 (Barton Marine Equipment Ltd., Whitstable, United Kingdom), which allowed the development  
190 of pulling actions away from the system as described by Cuenca-Fernandez, Ruiz-Teba, Lopez-  
191 Contreras, & Arellano (2018). The participants started the exercise in prone position on an  
192 inclined bench (45° from vertical) with both arms horizontally extended to the front and each  
193 hand holding a handle from the pulley system (Figure 1A). They were asked to perform a  
194 complete shoulder extension at maximal velocity, return to the starting position in a controlled  
195 manner, maintain the position for 0.5 seconds, and perform a second repetition. Every  
196 participant had to complete 2 repetitions with each load, increasing every 2 minutes. Through  
197 the linear encoder software, it was possible to obtain a prediction of the RM obtained from the  
198 first repetition. Therefore, the increments of the load were 10 kg at the beginning of the test and  
199 5 kg later (close to the maximal load). The test finished with the last load they could lift  
200 completely, and it was considered as the arm-stroke RM of the subjects ( $39.18 \pm 4.68$  kg). The  
201 relative load coefficient (Relative\_RM) was obtained by dividing the RM value achieved by  
202 each participant by their body weight. These two variables were considered as the strength-  
203 based dry-land variables. The additional velocity-based variables such as Mean propulsive

204 velocity (MPV), Mean propulsive power (MPP) and Mechanic impulse (IMP), were directly  
205 provided by the encoder.

206

207 On a second day, the participants moved on an experimental setting placed in a 25 m indoor  
208 pool (with water and air temperatures of 28.2 and 28.9° C, respectively). During this session, the  
209 swimming front crawl velocity with no load (NoLoadV) of the participants was collected. Each  
210 swimmer performed a 400m standardized warm-up consisting of 2x100m easy freestyle swim  
211 with 2 starts from the wall; 2x50m front crawl swim (12'5 fast; 12'5 smooth) and 100m front  
212 crawl at a normal pace followed by a dynamic stretching protocol both for the upper and the  
213 lower limbs as described by Cuenca-Fernandez, et al. (2018). Subsequently, they were tested on  
214 an in-water 25m all out swimming effort. One digital video camera (Sony Video Camera, 50Hz;  
215 Sony Electronics Inc., Tokyo, Japan), was installed on an underwater window at the poolside.  
216 This camera recorded the phase from 5 to 10 m. After the test, the velocity values were obtained  
217 from the underwater video files in Kinovea (Kinovea, version 0.7.10, France), as the distance  
218 from 5 to 10 m divided by the time elapsed during such action ( $1.75 \pm 0.08$  m/s). After that, the  
219 swimmers were given a first experience of two efforts in the semi-tethered device.

220

221 During a third session, the participants performed the same warm-up protocol and after 6 min of  
222 rest, they started the first trial of the STLS. The loads of the STLS were applied on the bar of an  
223 adapted Smith Machine connected to the swimmer's hip through a taut rope (Figure 1B). An in-  
224 water start was used and swimmers were instructed to reduce gliding. Although a previous study  
225 suggested that breathing patterns seem to not influence symmetry or performance in tethered  
226 swimming (N. M. Amaro, Morouço, Marques, Fernandes, & Marinho, 2017), the participants of  
227 this study were instructed to hold their breath during the effort in order to avoid any possible  
228 influence of this action on the encoder recordings. The test started with 1 kg of load (after the  
229 pulley system), and it was increased by successive 1 kg increments. Every trial ended when the

230 swimmers reached the maximal extension of the rope (15 m) and all the efforts had time  
231 duration of between 10 to 20 seconds. Six minutes of rest were given between trials (Hancock,  
232 et al., 2015). As every swimming effort produced the lift of the bar, it allowed to obtain through  
233 the encoder the velocity of swimming regarding the load added to the bar. The test finished  
234 when the lift of the bar produced swimming velocities under 0.65-0.55 m/s, as previous research  
235 recommended it avoidable (Dominguez-Castells and Arellano, 2012). The percentage of load  
236 pulled was estimated for every participant as the percentage of velocity loss regarding the  
237 velocity achieved with no load (Gonzalez-Badillo and Sanchez-Medina, 2010). Under this basis,  
238 the power/velocity vs. load curves were calculated at 15, 30, 45 and 60% ML. To avoid any  
239 effect of the impulse of the swimmer from the wall and the force asymmetries expected on the  
240 first cycles of the maximal swimming efforts (Morouço, Marinho, Fernandes, & Marques,  
241 2015), the first 4 arm-strokes were excluded and the 10 consecutive arm-stroke cycles were  
242 selected for further analysis.

243

244 (Please insert Figure 1 near here)

245

## 246 **VARIABLES MEASURED**

247

248 Average instantaneous velocity and acceleration were acquired from the encoder at a sampling  
249 rate of 1000Hz. Velocity and acceleration-time curves were smoothed using a fourth order  
250 Butterworth low pass digital filter, with a cut off frequency of 10 Hz, defined according to  
251 residual analysis (residual error versus cut-off frequency). The variations on the acceleration  
252 curves with respect to time were used to identify the arm-strokes performed by the swimmer.  
253 Every curve registered on the acceleration values above zero was considered as a one arm  
254 stroke. The maximal and minimum values of velocity were calculated as means  $\pm$  SD from



255 every arm stroke, obtained directly through the encoder used in 10 consecutive arm stroke  
 256 cycles ( $m \cdot s^{-1}$ ). The distance covered in 10 strokes (DC10St) was directly calculated as the time  
 257 to complete 10 strokes (T10St) multiplied by the velocity achieved.

258

259 The force delivered to the load was calculated according to Newton's second law (Equation 1),  
 260 where  $m$  stands for the load lifted on the Smith Machine in each situation and  $a$  stands for the  
 261 instantaneous variations on the acceleration registered by the encoder in the Smith Machine's  
 262 bar while lifting. The swimming power delivered to the load (average/peak) was calculated as  
 263 the force (average/peak) multiplied by the velocity delivered (average/peak).

264

265  $F = m \cdot a$       Equation 1

266

267 The impulse was calculated as the mean  $\pm$  SD of the values obtained in every single arm stroke  
 268 according to the equation 2. Where  $s$  stands for the beginning of the stroke (instant of the force  
 269 change),  $e$  for the end of the stroke and  $F$  stands for the force;  $\Delta t$  was 1/1000 (frequency of data  
 270 acquisition: 1000 Hz). The impulse normalized to the weight pulled (ImpRel) was obtained by  
 271 dividing the absolute values of impulse by the mass of the load pulled (in kg).

272

273  $\sum_s^e F \cdot \Delta t$       Equation 2

274

275 The intra-cyclic variation of the horizontal velocity of the hip ( $dv$ ) and the intra-cyclic variation  
 276 of the horizontal force exerted by the swimmer to the load pulled ( $dF$ ), was analyzed as  
 277 previously described by Morouco, et al. (2017), (Equation 3). Where  $x$  represents either the  
 278 mean swimming velocity or force,  $x_i$  represents either the instantaneous swimming velocity or

279 force,  $F_i$  represents the acquisition frequency 1/1000 (frequency of data acquisition: 1000 Hz),  
 280 and  $n$  is the number of measured strokes.

281

$$282 \quad dv \ \& \ dF = \frac{\sqrt{\frac{\sum i(x_i - \bar{x})^2 \cdot F_i}{n}}}{\frac{\sum i x_i \cdot F_i}{n}} \cdot 100 \quad \text{Equation 3}$$

283

## 284 STATISTICAL ANALYSES

285

286 Descriptive statistics were obtained and the data was expressed as mean  $\pm$  SD, confidence  
 287 intervals (CIs) (95%). The test-retest reliability (intraclass correlation coefficient [ICC]), within  
 288 and between observers was analyzed for the  $dv$ . Five trials (5 digitized by the researcher, and the  
 289 other 5 digitized by other researchers with experience in the processing computational routine),  
 290 were conducted on 10 swimmers who completed 4 trials with different loads. The intraobserver  
 291 ICC ranged between 0.95 (95% CI, 0.92 – 0.99) and 0.96 (95%, 0.92-0.98), and the  
 292 interobserver ICC ranged from 0.97 (95% CI, 0.96 – 0.98) to 0.99 (95% CI, 0.98 – 0.99) for the  
 293 tethered measurements.

294

295 The effect sizes ( $d$ ) of the obtained differences were calculated and categorized (small if  $0 \leq |d|$   
 296  $\leq 0.5$ , medium if  $0.5 < |d| \leq 0.8$ , and large if  $|d| > 0.8$  (Cohen, 1988). After Shapiro-Wilk testing  
 297 for normality distribution, repeated measures 1-way ANOVA tests were carried out to find  
 298 differences between the variables at 15, 30, 45 and 60% of the maximal load (ML). To detect  
 299 differences between variables, significance was accepted at the  $\alpha \leq 0.05$  level, and paired  
 300 comparisons were used in conjunction with Holm's Bonferroni method for controlling type 1  
 301 errors.

302

303 Pearson product-moment correlation coefficients ( $r$ ) were used to verify the relationship  
304 between the swimming velocities and the different sorts of strength-based and velocity-based  
305 variables obtained on the dry-land arm-stroke strength test. All statistical procedures were  
306 performed using SPSS 21.0 (IBM Chicago, IL, USA).

307

## 308 **RESULTS**

309

310 Mean, SD,  $P$  – values and Effect sizes for all tested STLS variables are presented in Table 1.  
311 Most of the variables were adversely affected by the load pulled. The velocity of swimming was  
312 different ( $F_{3,13} = 977.72$ ,  $p = 0.000$ ) and decreased along with the load pulled. In addition, the  
313 time to complete the ten arm-strokes ( $F_{3,13} = 12.616$ ,  $p = 0.000$ ) and the distance covered ( $F_{3,13} =$   
314  $307.22$ ,  $p = 0.000$ ) was also affected because both variables were progressively lower when  
315 increasing the load. The power values were different depending on the load (Mean:  $F_{3,13} =$   
316  $20.345$ ,  $p = 0.000$ ; Peak:  $F_{3,13} = 27.158$ ,  $p = 0.000$ ). The highest mean values were obtained at  
317 45% ML (Power:  $57.50 \pm 10.94$  W) (Figure 2), meanwhile the peaks were both found at some  
318 point between 30 and 45% ML. From that point onwards, the power values decreased (Table 1).

319

320 The values of Force, Acceleration, Impulse and ImpRel were different in every effort ( $p <$   
321  $0.05$ ). The highest values of force and impulse were obtained at 60% ML, while the highest  
322 values of Acceleration and ImpRel were acquired at 15% ML (Table 1). The  $dv$  values were  
323 different ( $F_{3,17} = 12.142$ ,  $P = 0.000$ ), although *post-hoc* only revealed a significant increase at  
324 60% ML ( $p < 0.002$ ) in comparison with the rest of the efforts. Finally, no differences were  
325 detected in  $dF$  as a consequence of increasing the load ( $F_{3,13} = 1.851$ ,  $P = 0.188$ ).

326

327 (Please insert Table 1 near here)

328

329 (Please insert Figure 2 near here)

330

331 The correlations between the velocity of swimming and the variables collected in dry-land  
332 conditions through the Smith Machine's device are shown in Table 2. Pearson's correlation  
333 coefficient detected a moderate to strong relationship between the RM and the Relative\_RM of  
334 the swimmers and the mean velocity with no load ( $r = 0.496$ ,  $p = 0.050$ ;  $r = 0.529$ ,  $p = 0.035$ ;  
335 respectively). Regarding the velocity achieved in the different STLS efforts, the RM only  
336 correlated with some swimming velocities manifestations at 60% ML, meanwhile the  
337 Relative\_RM achieved some correlations at 15 and 30% ML (Table 2). On the other hand, MPV  
338 and MPP reached strong and moderate correlations with the mean swimming velocity with no  
339 load ( $r = 0.709$ ,  $p = 0.002$ ;  $r = 0.564$ ,  $p = 0.023$ ; respectively). Furthermore, some other  
340 correlations were found between these variables with the maximum and minimum velocities  
341 achieved in the different STLS efforts (Table 2). The higher the velocity and power applied on  
342 the dry-land test, the higher the velocity of swimming, even at different loads. Finally, the IMP  
343 acquired on the arm-stroke dry-land exercise, reached a negative correlation with the velocity of  
344 swimming with no load ( $r = -0.554$ ,  $p = 0.026$ ) and some of the STLS efforts (Table 2). In this  
345 sense, high values of impulse in the dry-land exercise were associated with lower velocities of  
346 real swimming, especially with the maximum velocities achieved at 30, 45 and 60% ML ( $p <$   
347  $0.03$ ).

348

349 (Please insert Table 2 near here)

350

351 **DISCUSSION**

352

353 One of the purposes of our study was to present an updated protocol to assess semi-tethered  
354 swimming performance in front crawl. The power vs. load curves presented an inverted ‘U’  
355 shape (Figure 1), similar to those obtained by previous authors (Dominguez-Castells, et al.,  
356 2013; Garcia-Ramos et al., 2016). Nevertheless, although the peak power output was achieved  
357 at some point between the 30% ML ( $67.21 \pm 10.79$  W) and 45% ML ( $71.38 \pm 10.12$  W) ( $p =$   
358  $0.137$ ), the higher value of mean power was found at 45% ML (Figure 1), and it corresponded  
359 to a swimming velocity of  $0.95 \pm 0.06$  m/s. Those values were very similar to the ones obtained  
360 by Dominguez-Castells, et al. (2013) ( $66.49 \pm 19.09$  W), although they reported lower velocity  
361 values ( $0.75 \pm 0.18$  m/s). In addition, those results were achieved at a very similar load  
362 percentage (47% ML:  $3.95 \pm 0.79$  kg), although in the present study, that load percentage  
363 corresponded to a larger load mass (45% ML:  $6.00 \pm 0.98$  kg). The reasons to discuss it are two-  
364 fold; At first, it is important to consider that leg kicking was not restricted in our study and it  
365 obviously provides significant propulsion (Deschodt, Arsac, & Rouard, 1999; Morouço,  
366 Marinho, Izquierdo, et al., 2015). Moreover, it has been noted that leg kicking has a  
367 considerable influence on body-roll because it applies a torque on the hip that limits the hip  
368 rotation (Sanders and Psycharakis, 2009). Therefore, it may provide a higher stabilization in the  
369 development of the swimming movements (Psycharakis and Sanders, 2010). On the other hand,  
370 the resistance offered by the added mass may be higher underwater given the quadratic nature of  
371 the hydrodynamic drag (Marinho et al., 2009). In such case, the external work was higher not  
372 only because of the increases of the load, but also because of the drag offered by the dumbbell  
373 when accelerating (Dominguez-Castells, et al., 2013; Hollander et al., 1986).

374

375 By contrast, in the study of Johnson, et al. (1993), the resistance of the added mass was applied  
376 externally on a power rack, and the values were collected without inhibiting the leg actions.  
377 Such a method was more akin to what was applied in this study, however, the peak power

378 output was slightly higher than the maximal values achieved in this study ( $80 \pm 21$  W vs.  $71.38$   
379  $\pm 10.12$  W) and the load eliciting that peak power was significantly superior (7.8 kg) than the  
380 range of loads found in our study (4.37 – 6.00 kg). Possibly, since Power was calculated in both  
381 studies as  $(\text{Force} \cdot \text{Distance}) / \text{Time}$ , the differences would come from the procedure to obtain  
382 the Force value. In the study of Johnson, et al. (1993), it was calculated solely as the weight  
383 pulled by the swimmers, meanwhile in the present study, the Force values were determined  
384 according to Newton's second law ( $F = m \cdot a$ ). Therefore, the values achieved at high loads  
385 might have been countered by the low acceleration achieved (Table 1), and therefore, this may  
386 have influenced the outcomes obtained in Power.

387

388 Furthermore, according to the force-velocity relationship of the skeletal muscle, the outcomes  
389 obtained in Force and Impulse could be expected (Table 1), indicating that at very high velocity  
390 contractions, it is not easy to accumulate high amounts of force and impulse values and once the  
391 resistance loads grow, the force and impulse needed to overcome them increases (Dopsaj, et al.,  
392 2001; Garcia-Ramos, et al., 2016; Keskinen, Tilli, & Komi, 1989). Considering that any  
393 increase in swimming velocity requires a proportional increase in the applied muscle force to  
394 sustain such velocity (Vorontsov, et al., 2011), this fact may reflect an augmented quantity of  
395 the propulsive movements conveyed per stroke at high loads, a key that might be of success for  
396 sprinters (N. Amaro, et al., 2014; Dopsaj, et al., 2001). However, the loss of velocity and  
397 acceleration, together with the reduction of the distance covered and the time in the 10 arm-  
398 strokes were not in line with the increases obtained in force and absolute impulse at high loads  
399 but in line with the reduction of the Impulse normalized to the load pulled (ImpRel). Therefore,  
400 if STLS does not produce any increase on the propulsive skills, but deterioration on them, it  
401 should be highly reconsidered when including in-water resisted swimming routines, as little or  
402 no benefit may be obtained from them.

403

404 In any case, coaches should be aware that the application of different loads in STLS may affect  
405 the subjects' performance differently. Lower power production at fast velocities and low loads  
406 might indicate a high resistive drag and a low swimming efficiency, meanwhile a low power  
407 production at heavy loads and low velocities might indicate deficits in the swimmers strength  
408 (Dopsaj, et al., 2001; Johnson, et al., 1993). For that reason, another aim of this study was to  
409 examine the intra-cycle velocity ( $dv$ ) and force variation ( $dF$ ) along with the increasing loads.  
410 The  $dv\%$  and  $dF\%$  represents a balance between propulsive and resistive forces. The higher the  
411  $dv\%$  and  $dF\%$  the poorer the performance, as it represents a low-efficient application of the  
412 forces in the water (Barbosa et al., 2013). In our study, the highest  $dv\%$  was obtained at the  
413 highest load and lowest velocity. In fact, the deepest variation in  $dv\%$  was detected between 45  
414 to 60% ML ( $p < 0.001$ ), coinciding also with the loss of swimming power (Table 1). These  
415 results were expected. Sustaining high swim velocities is obviously hard while pulling heavy  
416 loads because the swimmer is unable to find the impulse needed to overcome the resistance in  
417 an unstable environment such as water. It implies increases in power and strength requirements  
418 of the muscles (e.g. with speed), which require stiffer tendons to produce optimal efficiency and  
419 the required power with a given muscle volume. The greater force generated by muscle is  
420 associated with the transmission of more stress through the tendon. Consequently, higher  
421 muscle requirements also produce higher fatigue and it may affect the swimming technique  
422 adversely (Cuenca-Fernandez, et al., 2018).

423

424 Morouco, et al. (2017) reported that swimmers with higher  $dv\%$  would also present higher  $dF\%$ .  
425 However, the  $dF\%$  did not change along with the increase of the load (Figure 2), and actually, it  
426 seemed to be slightly reduced as a consequence of it. Possibly, as the time to complete the 10  
427 arm-strokes was shorter at higher loads, it indicated that every arm-stroke was not only shorter,  
428 but also produced less propulsive impulse. This modification on the stroke patterns may be a  
429 consequence of the increased difficulty to transfer the force into the water at maximal or sub-  
430 maximal loads and would also be consistent with the results found in the present study for

431 ImpRel (Table 1). Nevertheless, previous studies have shown that semi-tethered swimmers may  
432 increase the coordination index by overlapping the arm strokes, and this effect may reduce the  
433 dF% (Dominguez-Castells and Arellano, 2012; Schnitzlerl, Seifert, Ernwein, & Chollet, 2008;  
434 Seifert, Chollet, & Bardy, 2004). Unfortunately, that variable was not measured in this study  
435 and future research should provide more information about this issue, testing also if swimmers  
436 with a high dF% may benefit from STLS practice to reduce it.

437

438 The associations found between the dry-land variables and the velocity of swimming (Table 2),  
439 are not new as previous studies have shown considerable interest in this field (Crowe, et al.,  
440 1999; Dominguez-Castells, et al., 2013; Garrido, et al., 2010; Perez-Olea, et al., 2018; Ravé, et  
441 al., 2018). In the study of Johnson, et al. (1993), the RM achieved on the *bench press* exercise  
442 was correlated with the swimming velocity ( $r = 0.55$ ), meanwhile in the study of Garrido, et al.  
443 (2010), a similar correlation was found ( $r = 0.58$ ) compared with the load at 6RM. However,  
444 both authors pointed out that the nature of the selected exercise was possibly not specific  
445 enough to expect that improvements in strength would result in improved swimming  
446 performance. In contrast, Crowe, et al. (1999), obtained higher correlations ( $r = 0.65$ ), between  
447 the RM obtained in *lat pull-down* (i.e. in a pulling exercise) and swimming performance  
448 measured in 50 meters. For that reason, despite RM being more related with maximum force  
449 than with explosive force, the associations between swimming velocity with the RM ( $r = 0.49$ )  
450 and Relative\_RM ( $r = 0.52$ ) were explored in this study through a pulling exercise, which would  
451 support the development of muscular strength in swimmers, as it appears to play an important  
452 role in the determination of maximal swim velocity.

453

454 Nevertheless, it is worthy of review that while the RM only showed moderate to strong  
455 correlations with V60 ( $r = 0.68$ ) and Vmin60 ( $r = 0.52$ ) (i.e. at higher loads), the Relative\_RM,  
456 reached correlations with V15 ( $r = 0.52$ ), Vmin15 ( $r = 0.52$ ) and V30 ( $r = 0.54$ ) (i.e. at lower  
457 loads). Since the fact that producing a high percentage of Relative\_RM is the greater capacity of



458 force due to lower body weight, the Relative\_RM index may reflect with more accuracy the  
459 strength abilities of the swimmers (Cuenca-Fernández et al., 2015). Possibly, considering that  
460 higher swimming velocities were achieved at low loads (Table 1), the correlation with the  
461 Relative\_RM index may also reflect that those swimmers presented a lower surface area and  
462 hydrodynamic drag than the average (Hollander, et al., 1986). At 60% ML, under a severe  
463 reduction of swimming velocity ( $p < 0.000$ ) and consequently in the drag acting against the  
464 body (Marinho, et al., 2009), the RM of the swimmers was shown as a predictor to achieve and  
465 maintain a higher swimming velocity (Table 2). It may indicate that regardless of their strength  
466 abilities, the swimmers with a high value of Relative\_RM may presumably offer less drag than  
467 the average and it would be more reliable than testing only the RM to predict real swimming  
468 performance. Moreover, it would offer a valid and different rationale arguing why studies  
469 testing performance in tethered swimming (i.e. with no drag acting against the body) have  
470 shown to be more related with the absolute force values rather than with the relative ones  
471 (normalized to body mass) (Morouco, et al., 2011).

472

473 On the other hand, as movement velocity has shown to be a predictor of loading intensity and  
474 strength capability in resistance training (Gonzalez-Badillo and Sanchez-Medina, 2010),  
475 different velocity-based perspectives have been carried out to link performance obtained in dry-  
476 land conditions with actual swimming. Morouco, et al. (2011), found correlations ( $r = 0.68$ )  
477 between MPP in *lat pull down* and velocity of swimming in 50m. Meanwhile, in the study of  
478 Dominguez-Castells, et al. (2013) the maximum power obtained on a dry-land arm-stroke  
479 exercise, was relatively similar to maximum swim power ( $r = 0.91$ ), and both of these power  
480 values were related to swim velocity ( $r = 0.85$ ,  $r = 0.72$ ). On the other hand, Perez-Olea, et al.  
481 (2018) recently demonstrated that the mean velocity reached in a test of maximal number of  
482 *pull-ups* correlated with swimming velocity ( $r = 0.88$ ), and the relative loss of velocity during  
483 the pull-up test accounted for 84% ( $p < 0.001$ ) of 50m freestyle performance variance. Thus,  
484 those results were in agreement with the ones obtained in this study as two of the velocity-based  
485 variables, MPV and MPP, correlated with different velocities achieved at different STLS efforts

486 (Table 2). Meanwhile, the negative correlation obtained between IMP and swimming velocity  
487 indicated that for a given force in N, the lower the velocity of the arm-stroke, the higher the time  
488 spent to complete the movement. Therefore, considering that swimming is characterized by  
489 producing fast movements in a short period of time, especially when sprinting (Seifert, et al.,  
490 2004), velocity-based dry-land variables may constitute an effective approach to predict actual  
491 swimming performance.

492

493 The results of the present investigation have shown that STLS alters the swimming kinetics and  
494 kinematics. A reduction of the time spent per stroke is obtained due to loaded swimming and it  
495 seems not possible to achieve the higher requirements of force/impulse needed to overcome the  
496 high loads. Those alterations seem to be higher from 45% ML onwards, with greater increases  
497 in critical variables as  $dv\%$  which indicated a high difficulty to maintain a constant speed in the  
498 water and a deep deterioration in performance. Therefore, STLS should be cautiously  
499 administered to include specific high-intensity force development programs, since its transfer to  
500 improve the biomechanical skills of the swimmers seems questionable. Regarding the results  
501 obtained in the dry-land test, the swimmers with higher index of relative strength may obtain  
502 better results in STLS at low loads and higher speed, although the ability to develop a high  
503 amount of absolute strength seems relevant for swimmers. Possibly, as the velocity obtained  
504 when pulling a low resistance in the STLS likely reflects the combined contribution of the  
505 propulsive skills and minimized body drag, the improvement in either of these components  
506 could result in improved swimming performance scores. In any case, swimming performances  
507 seem to be better predicted through dry-land exercises which allow the development of high  
508 speed and explosive movements, possibly because actual swimming movements are produced  
509 quickly and intensely in a short period of time.

510

511 This study presented some limitations, as the correlations presented here were obtained  
512 according to swimmers' upper limb strength; however, the semi-tethered encoder recordings  
513 might not just be from the arm action throughout the underwater stroke, but also from the leg

514 action. On the other hand, although participants had one previous practice with the STLS  
515 device, it was possible not enough to get familiarized enough with it. Nevertheless, a simple  
516 adaptation of a system used to measure performance in dry-land conditions allowed us to  
517 measure performance in swimmers. Moreover, this system has shown to be sensitive in  
518 obtaining valuable information about intra-cyclic velocity or force variation, which could lead  
519 coaches to focus on improving swimmer's technique rather than increasing physical  
520 conditioning.

521

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523

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528

## 529 **DECLARATION OF INTEREST STATEMENT**

530

531 No potential conflict of interest was reported by the authors.

532

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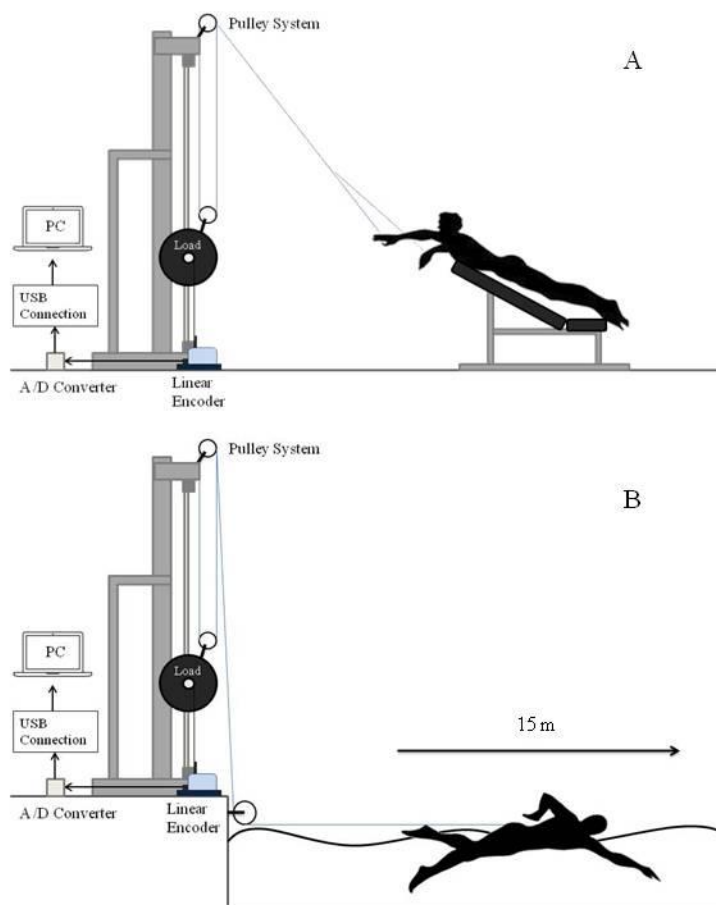
**Table 1.** Mean, SD and P – value for the variables obtained from the semi-tethered loaded swimming test at 15, 30, 45 and 60% of the maximal load (n=16).  
(\* $P < 0.05$ )

	Load 15%	<i>Versus</i>	Load 30%	<i>Versus</i>	Load 45%	<i>Versus</i>	Load 60%	P value (ANOVA)
	Mean $\pm$ SD 95% CIs	P value (Post Hoc) Effect Size (95% CI)	Mean $\pm$ SD 95% CIs	P value (Post Hoc) Effect Size (95% CI)	Mean $\pm$ SD 95% CIs	P value (Post Hoc) Effect Size (95% CI)	Mean $\pm$ SD 95% CIs	
Load Pulled (Kg)	2.31 $\pm$ 0.62 (1.97-2.64)	0.000 2.79 (1.41, 4.16)	4.37 $\pm$ 0.84 (3.92-4.82)	0.000 1.78 (0.62, 2.94)	6.00 $\pm$ 0.98 (5.47-6.52)	0.000 1.31 (0.23, 2.39)	7.37 $\pm$ 1.10 (6.78-7.96)	0.000*
DC10St (m)	14.10 $\pm$ 1.25 (13.43-14.77)	0.000 -1.93 (-3.12, -0.74)	11.59 $\pm$ 1.34 (10.88-12.31)	0.000 -2.03 (-3.24, -0.82)	8.59 $\pm$ 1.60 (7.74-9.45)	0.000 -1.49 (-2.60, -0.38)	6.72 $\pm$ 0.76 (6.31-7.13)	0.000*
T10St (s)	9.59 $\pm$ 0.84 (9.13-10.04)	1.0 -0.06 (-1.04, 0.91)	9.53 $\pm$ 1.01 (8.99-10.07)	0.736 -0.35 (-1.34, 0.63)	9.16 $\pm$ 1.07 (8.59-9.74)	0.029 -0.48 (-1.47, 0.51)	8.67 $\pm$ 0.95 (8.16-9.18)	0.000*
Velocity (m/s)	1.47 $\pm$ 0.06 (1.44-1.51)	0.000 -4.33 (-6.12, -2.54)	1.21 $\pm$ 0.06 (1.18-1.25)	0.000 -4.33 (-6.12, -2.54)	0.95 $\pm$ 0.06 (0.92-0.99)	0.000 -4.31 (-6.10, -2.52)	0.73 $\pm$ 0.04 (0.71-0.75)	0.000*
Force (N)	23.40 $\pm$ 6.48 (19.95-26.86)	0.000 3.19 (1.71, 4.67)	43.52 $\pm$ 8.54 (38.97-48.08)	0.000 1.77 (0.61, 2.92)	59.42 $\pm$ 9.38 (54.42-64.42)	0.000 1.28 (0.21, 2.36)	72.46 $\pm$ 10.83 (66.69-78.24)	0.000*
Acceleration (m/s <sup>2</sup> )	0.30 $\pm$ 0.11 (0.24-0.36)	0.048 -0.85 (-1.88, 0.16)	0.21 $\pm$ 0.10 (0.15-0.27)	1.0 -0.21 (-1.19, 0.77)	0.19 $\pm$ 0.09 (0.14-0.24)	0.000 -0.99 (-2.03, 0.04)	0.11 $\pm$ 0.07 (0.07-0.15)	0.000*
Power (W)	34.34 $\pm$ 9.96 (29.03-39.65)	0.000 1.71 (0.57, 2.86)	52.44 $\pm$ 11.08 (46.53-58.35)	0.050 0.46 (-0.53, 1.45)	57.50 $\pm$ 10.94 (51.67-63.34)	0.000 -0.42 (-1.41, 0.56)	53.12 $\pm$ 9.81 (47.89-58.35)	0.000*
Peak Power (W)	49.24 $\pm$ 9.62 (50.73-63.81)	0.000 1.75 (0.60, 2.91)	67.21 $\pm$ 10.79 (62.16-80.36)	0.137 0.39 (-0.59, 1.38)	71.38 $\pm$ 10.12 (68.14-91.39)	0.000 -0.62 (-1.63, 0.37)	65.25 $\pm$ 9.44 (66.20-87.53)	0.000*
Impulse (N·s)	15.97 $\pm$ 3.55 (14.08-17.86)	0.001 1.62 (0.49, 2.75)	21.93 $\pm$ 3.78 (19.92-23.95)	0.004 1.11 (0.06, 2.17)	27.08 $\pm$ 5.30 (24.26-29.91)	0.011 0.41 (-0.57, 1.40)	29.50 $\pm$ 6.23 (26.18-32.82)	0.000*
ImpRel (N·s/Kg)	7.49 $\pm$ 2.82 (5.99-8.99)	0.008 -1.03 (-2.08, 0.00)	5.17 $\pm$ 1.42 (4.41-5.93)	0.292 -0.53 (-1.53, 0.45)	4.56 $\pm$ 0.74 (4.16-4.96)	0.009 -0.85 (-1.87, 0.17)	3.99 $\pm$ 0.59 (3.68-4.31)	0.001*
dv (%)	39.62 $\pm$ 10.75 (33.89-45.35)	1.0 0.39 (-0.59, 1.38)	43.56 $\pm$ 9.41 (38.54-48.57)	0.787 0.43 (-0.55, 1.42)	47.65 $\pm$ 9.38 (42.65-52.65)	0.000 1.15 (0.09, 2.21)	58.91 $\pm$ 10.13 (53.51-64.31)	0.000*
dF (%)	6.84 $\pm$ 1.68 (5.95-7.74)	1.0 0.33 (-0.54, 1.22)	6.40 $\pm$ 1.24 (5.74-7.07)	0.338 -0.25 (-1.13, 0.62)	5.83 $\pm$ 1.21 (5.19-6.48)	0.734 -0.18 (-1.06, 0.69)	5.38 $\pm$ 1.72 (4.46-6.30)	0.188

**Table 2.** Pearson's correlation coefficients and P-value between velocity of swimming (Mean, maximum and minimum) obtained from the semi-tethered loaded swimming test (at 15, 30, 45 and 60% of the maximal load) and variables obtained through the dry-land arm-stroke test conducted on the Smith Machine's device; Maximal (RM) and relative dry-land load (Relative\_RM); mean propulsive velocity (MPV), mean propulsive power (MPP) and; impulse (IMP) (n=16). \*P < 0.05

	Mean $\pm$ SD	RM		Relative_RM		MPV		MPP		IMP	
		r	p	r	p	r	p	r	p	r	p
NoLoadV	1.75 $\pm$ 0.08	0.496	0.050*	0.529	0.035*	0.709	0.002*	0.564	0.023*	-0.554	0.026*
V15	1.47 $\pm$ 0.06	0.442	0.086	0.528	0.036*	0.664	0.005*	0.501	0.048*	-0.417	0.108
VMax15	1.97 $\pm$ 0.14	0.229	0.393	0.044	0.873	0.421	0.104	0.241	0.369	-0.468	0.067
VMin15	1.00 $\pm$ 0.15	0.300	0.258	0.520	0.039*	0.793	0.000*	0.279	0.296	0.105	0.699
V30	1.21 $\pm$ 0.06	0.364	0.165	0.426	0.100	0.344	0.192	0.711	0.002*	-0.585	0.017*
VMax30	1.76 $\pm$ 0.18	0.405	0.120	0.361	0.170	0.175	0.518	0.035	0.898	-0.612	0.012*
VMin30	0.64 $\pm$ 0.15	0.426	0.100	0.544	0.029*	0.163	0.546	0.314	0.236	0.103	0.703
V45	0.95 $\pm$ 0.06	0.451	0.079	0.366	0.163	0.665	0.005*	0.473	0.064	-0.472	0.065
VMax45	1.47 $\pm$ 0.18	0.400	0.125	0.427	0.099	0.502	0.047*	0.199	0.461	-0.678	0.004*
VMin45	0.42 $\pm$ 0.11	0.202	0.453	0.100	0.712	0.121	0.656	0.232	0.387	0.068	0.803
V60	0.73 $\pm$ 0.04	0.681	0.004*	0.438	0.090	0.506	0.046*	0.480	0.060	-0.410	0.115
VMax60	1.19 $\pm$ 0.15	0.362	0.169	0.474	0.064	0.429	0.097	0.190	0.481	-0.523	0.038*
VMin60	0.21 $\pm$ 0.06	0.522	0.038*	0.399	0.126	0.395	0.130	0.438	0.090	-0.144	0.595

**Figure 1.** Layout of the dry-land (A) and aquatic (B) protocols, designed to evaluate performance of the swimmers through the adaptation of a linear encoder.



**Figure 2.** Average power/velocity/force vs. load curve (Above); Average intracyc velocity & force variation (dv/dF) vs. Maximum & minimum velocity values (Below), obtained from the semi-tethered loaded swimming test at 15, 30, 45 and 60% of the maximal load. The actual loads of that percentage corresponded to 2.31, 4.37, 6.00 and 7.37 kg, respectively (n=16). \*P < 0.05

