STRENGTH-VELOCITY RELATIONSHIP OF RESISTED SWIMMING: A REGRESSION ANALYSIS

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This study explored how external loads affect semi-tethered resisted swimming (STRS). Twenty national competitive swimmers (age: 18.31 ± 1.42 years) participated in an incremental STRS test. *Pearson* product-moment correlation coefficients between the load and the swimming variables were obtained, and simple linear regression analyses were applied to evaluate the associations. The results showed that less velocity and acceleration were delivered at high loads ($p < 0.001$). It increased the velocity fluctuation, affecting the swimming patterns adversely. A decrease in the impulse relative to the load pulled is obtained, especially after 20-30% of the maximal load ($R^2 = 0.724$, $p < 0.000$). Coaches should reconsider using STRS, as little benefits may be obtained in performance.

KEY WORDS: Swim Power, Strength development, Performance assessment.

INTRODUCTION: The nature of a swimmer's locomotion lies in the hydrodynamic reaction forces created by the swimmer's limb movements to overcome water resistance (Vorontsov & Rumyantsev, 2000). This means that the speed of swimming will depend on the balance between the magnitude and direction of the propulsive forces acting against the hydrodynamic resistance. In this regard, Semi-tethered Resisted Swimming (STRS) has been proposed as a valid tool to elicit high-intensity resistance training under the assumption that increases in external resistance could directly impact the development of hydrodynamic reaction forces and thus, improve propulsion (Amaro, Marinho, Batalha, Marques, & Morouco, 2014). Previous studies conducted under tethered swimming conditions (i.e. without displacement), have reported that the relationship between maximum impulse (taken through cell-force) and swimming speed (gathered in normal conditions) tends to be linear (Morouco, Marinho, Keskinen, Badillo, & Marques, 2014). Thus, increases in swimming velocity would correspond to a proportional increase in the applied muscle force to sustain such speed (Vorontsov, Seifert, Chollet, & Mujika, 2011). While we believe this proposal has merit, we may also suggest that this would force a dual path in which the force-velocity relationship of skeletal muscle could be misinterpreted with the force effectively transferred into the water and it's capability to cause propulsion. For example, a high force output when pulling heavy loads in STRS would reflect a large amount of propulsion conveyed per stroke and should be in line with high swimming speed, but this does not occur, given that swimmer's acceleration is severely reduced at such loads. Our hypothesis is that, as STRS allows displacement and movement velocity has shown to be a predictor of loading intensity and strength capability in resistance training (Gonzalez-Badillo & Sanchez-Medina, 2010), an acceleration-based approach could provide different insights about the load-force and velocity relationship of STRS, as it would collect the data generated by the effective swimmer's propulsion. For that reason, the purpose of this study was to study the changes that occur in the kinetic and kinematic swimming variables during incremental STRS protocol in order to know if increasing loads would produce a development of the propulsive impulse.

METHODS: Twenty national competitive male swimmers (18.41 ± 1.31 years; 71.46 ± 9.08 kg; 1.81 ± 0.02 m; > 5 years experience); provided signed consent to participate in an incremental STRS test consisted of several swimming efforts to 15 m. The maximal load (ML: 7.18 ± 1.04 Kg), was considered when the loss of velocity was higher than

60% achieved with no load (Dominguez-Castells & Arellano, 2012). The experiment placed in a 25m pool (water and air temperatures of 28.2 and 28.9º C). At arrival, swimmers performed a standard warm-up consisting of varied swimming followed by dynamic limbs stretching. Then, participants started the first effort of the incremental STRS test. Swimmers were connected to a waist belt attached to a Smith Machine (Jim Sports Technology S.L., Lugo, Spain) by using a taut rope and a pulley system. A linear encoder (T-Force Dynamic Measurement System, Ergotech, Murcia, Spain) was connected to the Smith Machine's bar to acquire velocity-time data during the efforts. Every effort produced automatically lifted the bar and a displacement registered by the encoder cable. Neither push-off from the wall, nor breathing, was allowed. The test started with 1 kg (after the pulley system), and it was increased by successive 1 kg. Five minutes of rest were given between efforts (n = 6.8 ± 1.37 efforts).
Velocity (V), acceleration (Accel) and force (F) were directly provided by the encoder and calculated as the means obtained on 10 arm-strokes (The first 2 arm-strokes were excluded). Every curve registered above zero in the Accel values was considered as a one arm stroke. A trapezoidal integration regarding time was used to calculate the acceleration impulse for each stroke with a frequency of data acquisition: 1000Hz. Then this value was averaged to 10 arm-strokes (ImpAc). The acceleration and impulse were normalized to the load (Accel_Load; ImpAc_Load) by dividing the absolute values of Accel and ImpAc by the mass of the load pulled (in kg). The stroke rate (SR) was calculated as 10 arm strokes divided by the time elapsed during this action (Stroke time: ST), and multiplied by 60 (to obtain the rate in cycle/min). The stroke length (SL) was determined by dividing mean V by mean ST. The number of strokes needed to complete 5 m (St5M) was calculated as the distance of 5 m divided by mean SL. The time to complete 5 m (T5M) was calculated as the distance of 5 m divided by mean V. The intra-cyclic velocity and force variation (IVV; IFV) were analyzed as shown in Equation 1, where *x* represents the mean velocity or force, x_i represents either the instantaneous velocity or force, *Fi* represents the acquisition frequency 1/1000, and *n* was the number of measured strokes (Morouco, Barbosa, Arellano, & Vilas-Boas, 2017).

$$IVV\ \&\ IFV = \frac{\frac{\sqrt{\sum i(x_i - \bar{x})^2 \cdot F_i}}{n}}{\frac{\sum i x_i \cdot F_i}{n}} \cdot 100 \qquad \text{Equation 1}$$

Pearson product-moment correlation coefficients between all variables were obtained, and simple linear regression analyses were applied to evaluate the potential associations. Significance was accepted at the alpha level $p \leq 0.05$. Analyses were performed using SPSS 21.0 (IBM Chicago, IL, USA). The test-retest reliability (intraclass correlation coefficient [ICC]), within and between observers was analyzed for the IVV. Five trials were conducted on 10 swimmers who completed 4 trials with different loads. The intraobserver ICC ranged between 0.95 (95% CI, 0.92 – 0.99) and 0.96 (95%, 0.92-0.98), and the interobserver ICC ranged from 0.97 (95% CI, 0.96 – 0.98) to 0.98 (95% CI, 0.97 – 0.99).

RESULTS: A decrease in velocity was obtained in tandem with the progressive increase of the load (Table 1). The negative correlation between the load and SL and the positive correlation for T5M and St5M indicated deterioration in performance. The regression analysis revealed an association between the increase of the load with IVV (Figure 1B), consistent with the negative Pearson's correlation obtained between IVV and V. The lowest values of IFV were at the lowest velocity (Table 1). The correlation between the increase in the load and the loss of acceleration was weak with Accel_Avg and moderate with Accel_Load. While ImpAc did not obtain correlations, ImpAc_Load was associated with the increase of the load (R^2 = 0.797, P = 0.001) and this correlated strongly with velocity.

Table 1. Pearson's correlation coefficients between load and swimming variables.

	V (m/s)	ST (s)	SR (cyc/min)	SL (m)	T5M (s)	St5M (s)
LOAD	-0.970* P < 0.001	-0.256* P < 0.001	0.250* P < 0.001	-0.936* P < 0.001	0.938* P = 0.001	0.902* P < 0.001
	IVV (%)	**IFV (%)**	**Accel_Avg (m/s^2)**	**ImpAc ($m/s^2 \cdot s$)**	**Accel_Load ($[m/s^2]/kg$)**	**ImpAc_Load ($[m/s^2 \cdot s]/kg$)**
	0.491* P < 0.001	-0.442* P < 0.001	-0.381* P < 0.001	-0.071 P = 0.401	-0.705* P < 0.001	-0.833* P < 0.001
	% Max Load	**ST (s)**	**SR (cyc/min)**	**SL (m)**	**T5M (s)**	**St5M (s)**
VEL	-0.970* P < 0.001	0.144 P = 0.066	-0.148 P = 0.059	0.915* P < 0.001	-0.962* P < 0.001	-0.886* P < 0.001
	IVV (%)	**IFV (%)**	**Accel_Avg (m/s^2)**	**ImpAc ($m/s^2 \cdot s$)**	**Accel_Load ($[m/s^2]/kg$)**	**ImpAc_Load ($[m/s^2 \cdot s]/kg$)**
	-0.471* P < 0.001	0.507* P < 0.001	0.425* P < 0.001	0.131 P = 0.121	0.597* P < 0.001	0.793* P < 0.001

DISCUSSION: A new procedure of STRS testing was presented. According to Dominguez-Castells and Arellano (2012), the loads above 60% ML should be avoided in STRS to ensure a constant swimming speed and stroke-coordination. However, our results showed alterations in swimming kinetics and kinematics, even at low loads.
Load increments constituted small variations in SR but large deterioration in SL, which meant that swimmer's arm strokes were shortened (Figure 1A). In addition, swimmers needed more time and a greater number of arm-strokes to cover a distance of 5 m, so the increment of the load possibly caused a slippery effect in the swimming patterns.

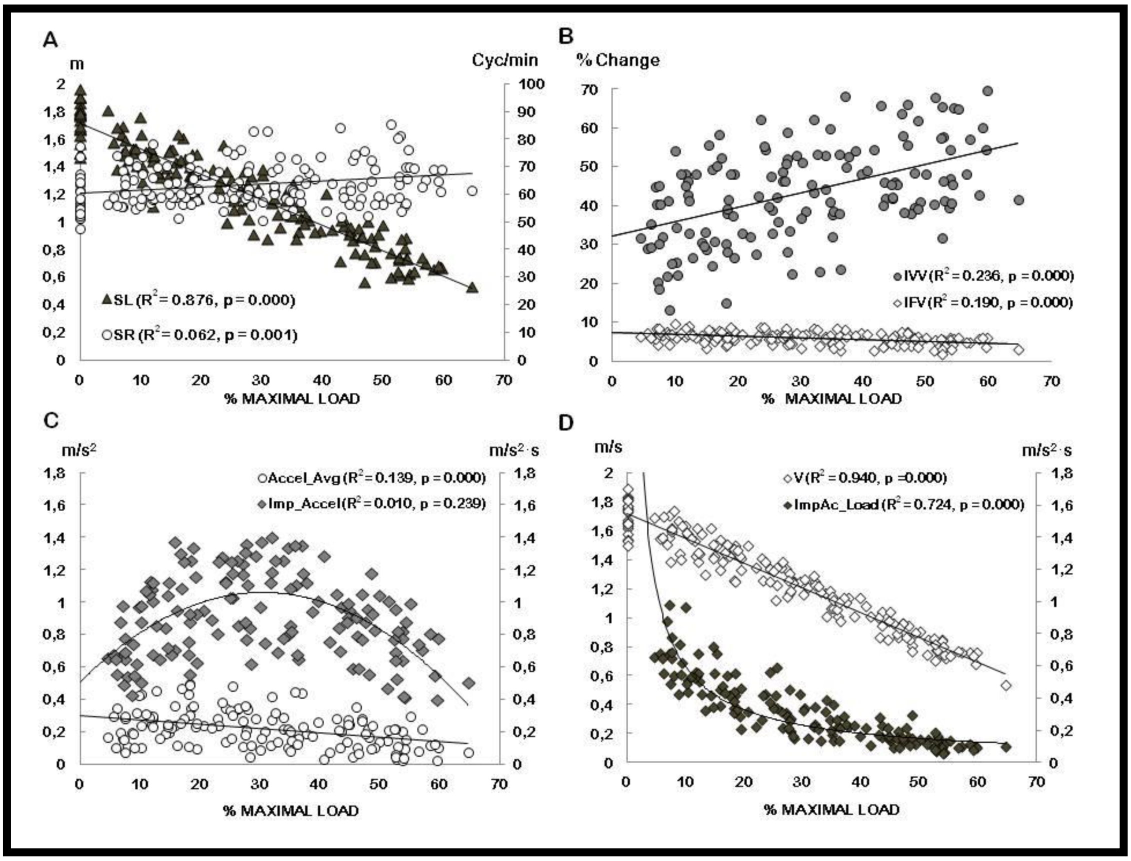

Figure 1. Regression analysis between the increase of the load and swimming variables.

Regarding the values obtained for IVV, they increased along with the load, while the velocity of swimming decreased as a consequence of it (Figure 1B). This was in agreement with previous literature (Morouco et al., 2017), and is based on an increase of the differences within the stroke cycle in terms of the ability to overcome the

resistance. According to some authors (Barbosa et al., 2013; Morouco et al., 2017), this would lead to deteriorated performance, since extra energy should be delivered to overcome the inertial forces. However, the IFV decreased along with increase in the load, but it may be attributed to general reduction of the forces applied in the water.
Participants of this study achieved the maximal ImpAc at 20-30% ML. It followed an inverted ‘U’ shape reaching its maximum at 25.63 ± 7.63% ML. However, this outcome neither correlated with the swimming velocity (Table 1), nor produced higher Accel_Avg (Figure 1C). Therefore, this deterioration was contradictory with the relationship previously reported between swimming speed and maximum impulse (Morouco et al., 2014). Eventually, when this variable was normalized to the mass of the load (ImpAc_Load), it followed a general decrease along with the loss of velocity. In this case, the pattern described a concave upward curve (Figure 1D), initially presenting a more rapid decrease, followed by a more gradual decrease at the end of the exercise. Although this indicated some adaptability at low loads (from 5 to 30% ML), high difficulties were displayed to be able to successfully pull high loads in the water.

CONCLUSION: This study estimated the effect of increasing external resistance in STRS through the swimming velocity collected with a linear encoder. This might be of interest to coaches when including parachutes, elastic cords, or drag suits, because they should avoid a loss of velocity higher than 20-30%; after this range, it does not seem possible to achieve the higher requirements of impulse needed to overcome the high loads in the water. It produced a critical deterioration in the swimming patterns which indicated a high variability and difficulties to maintain a constant speed. Thus, considering the strength-velocity relationship of resisted swimming, little or no benefit may be obtained given that performance is adversely affected.

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ACKNOWLEDGMENTS: This work was supported by the projects DEP 2014-59707-P “SWIM: Specific Water Innovative Measurements” and PGC2018-102116-B-I00 “SWIM II”, granted by the Spanish Research Agency and European Regional Development Fund (ERDF).