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Post high intensity pull-over semi-tethered swimming potentiation in national competitive swimmers

Running title: Pull-over potentiation in semi-tethered swimming

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ABSTRACT

BACKGROUND: The swimming community has shown considerable interest in using dry-land warm-ups as a method of impacting performance. This study compared the effects of high-resistance pull-over and swimming warm-up in semi-tethered resisted swimming.

METHODS: An incremental-load semi-tethered swimming test was individually administered in 20 national-competitive swimmers to determine the load maximizing swimming power. In different sessions, participants tested such a load 6 min after a swimming warm-up (SWU) or a dry-land warm-up (DLWU: 3 pull-over reps at 85% of the one-repetition maximum). Kinetic variables (velocity, force, acceleration, impulse, power rate of force development (RFD) and intra-cycle variation), were obtained with a linear encoder through trapezoidal integration regarding time. Kinematic variables (distance, time, stroke-rate and stroke-length), were obtained by video recordings. The differences between protocols were observed by paired-samples T-test (ANOVA). Pearson's coefficient explored correlations between kinetics and kinematics variables; significance was set at $P<0.05$.

RESULTS: DLWU increased RFD (34.52±16.55 vs. 31.29±13.70 N/s; $\Delta=9.35\%$) and stroke-rate (64.70±9.84 vs. 61.56 ± 7.07 Hz; $\Delta=5.10\%$) compared to SWU, but decreased velocity, force, acceleration, impulse and power. During the incremental-load test velocity and power were higher than obtained after SWU (1.21±0.14 vs. 1.17±0.12 m/s; $\Delta=3.06\%$), (51.38±14.93 vs. 49.98±15.40 W; $\Delta=2.72\%$), suggesting enhancements prompted by the test itself. Correlations between stroke-length with impulse ($r=0.76$) and power ($r=0.75$) associated kinetics with kinematics.

CONCLUSIONS: Potentiation responses were present after the dry-land warm-up. However, swimmers may benefit more from submaximal prolonged conditioning activities such as resisted swimming rather than high-resistance dry-land sets to obtain performance enhancements.

Key words: Sports, Exercise, Muscle fatigue, Physical exertion

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INTRODUCTION

The use of high-intensity conditioning exercises (CEs), as a method of short-term enhancements in the subsequent task, has been reported in the current literature as post-activation performance enhancement (PAPE) (1). After recent contractile history, muscles are in both a potentiated and fatigued state. However, fatigue dissipates faster than potentiation, creating an augmented muscular prevalence for possible performance enhancement (2). Several mechanisms may influence PAPE, including the effect of elevating the muscle temperature on the cross-bridge cycling rates (3, 4); the increases in motoneuron excitability detected after voluntary contractions (5, 6); or the increase in circulating hormones as epinephrine or norepinephrine after brief bouts of intense exercise (7).

The training PAPE principles are based on *complex training* (8), which consists of providing a resistive CE as similar as possible to the real action before performing a sport-specific activity involving the same muscle groups at a later time (5). Considering that some dry-land exercises involving mainly pulling actions have been shown to be effective predictors of swimming performance (9-12), this led some authors to test them as means to create CEs to potentiate swimming. However, the results were marginally unsuccessful (13, 14). The swimmer's performance does not depend solely on the capacity of the muscle system to produce large amount of power, but also on the ability to transfer it into the water to create effective propulsion (15-17). Therefore, it is still uncertain if swimmers may benefit from these methods to increase performance.

One critical aspect of using pulling-CEs is that the underwater path in swimming is not in a straight line from the front to the back (17). As swimmers search for steady water using a certain amount of sculling like movements to create effective propulsion, the capacity of a dry-land pulling-CE to reproduce the specific movements of the underwater arm-pull could be questioned (15, 18). Nevertheless, a fluid dynamics study reported that contrary to

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accepted notions in swimming, pronounced lateral movements could decrease the contribution of drag forces to thrust, reducing the effectiveness of the arm-pull (19). Therefore, this could provide an argument in favour of keep trying this kind of procedures with swimmers.

The analysis of the literature reveal that some other resistance training approaches have been shown to have a positive impact on swimmers, even without applying biomechanically-similar CEs (15, 20, 21). In addition, the main regulatory PAPE responses have been recently unrelated to the localized effects caused by post-activation potentiation (PAP) (5, 22), a muscle response mechanism originated by the contraction-induced effects in the muscle-myosin head phosphorylation (23). Thus, there is no evidence supporting the need to achieve full simulation of the real movement during conditioning protocols to induce PAPE, but rather evidence in favor of sufficient stimulation of the muscle system to achieve those responses (1, 5, 24).

On the other hand, the common limitations found in some PAPE-swimming studies are that the conclusive assumptions are based solely on the effects of the CEs on the kinematic variables of swimming (velocity, distance, time, stroke-rate and stroke-length) (13, 14, 25, 26), while the kinetic variables (force, acceleration, impulse, power and RFD) are rarely evaluated or only collected in tethered conditions (i.e. without displacement) (27), which it limits the possibility of exploring the hypothetical performance enhancements caused by the PAPE effects. Thus, this forces a path in which the biological or physiological effects prompted by the CEs could be biased by an inadequate procedure to detect those changes.

Recently, two potentiation approaches carried out in competitive male swimmers have obtained significant results in kinetic variables measured in real swimming conditions: i) swimming arm-pull thrust (Δ=18.73%), after an elastic band arm-pull protocol (16); and ii) in flutter kick thrust (Δ=15%) after an unloaded countermovement jump protocol (28). In

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both studies human thrust was measured through differential pressure sensors placed on hand and/or legs and the improvements in kinetic variables corresponded to low to moderate positive influences on speed (Δ=2-10%), respectively. Consequently, the authors concluded that PAPE protocols could improve swimming performance. While we believe that these proposals have merit and could re-orientate the way to assess potentiation responses in the water, acquiring such sophisticated equipment could be difficult for some population.

Therefore, considering that it would be preferable to test kinetic variables through familiar procedures (16), the fact that inspired the assessment tool applied in this study was based on another study that also obtained improvements through a different PAPE approach that could be equally valid for increasing swimmers performance (26). The conditioning protocol consisted on 4 x 10-m maximal semi-tethered resisted swimming efforts and the participants obtained improvements in 100-m freestyle performance (-0.54 s). In this regard, although the semi-tethered resisted efforts were designed as the CE, it could provide an alternative way of evaluating PAPE responses given its specificity and sensitivity in monitoring the similar muscular activity to that of free swimming (9, 12, 26).

For those reasons, the aim of this study was to investigate whether muscular performance could be improved after a dry-land or an aquatic warm-up in semi-tethered resisted swimming (STRS). Our hypothesis was that, if the kinetic energy is transferred directly to the water to produce the swimmers displacement, then the data collected by STRS would reflect the effective swimmers propulsion. Consequently, this could shed more light about the presence or not of potentiation responses in the kinetic variables of swimming.

MATERIALS AND METHODS

Participants

Twenty competitive male swimmers were fully informed about the experimental procedures and voluntarily provided signed informed consent to participate in this study (mean±standard

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deviation (SD)): 18.02±1.39 years; 70.36±8.97 kg; 1.80±0.04 m; 74.29±7.89% performance level of the world record (50-m Freestyle, Short course); FINA points: 477±163 points. Swimmers under 18 years of age were asked to provide signed parental consent. The exclusion criteria included: i) swimmers without at least one national-level competitive participation in the last year; ii) participants who have suffered any injury or disease in the past 6 months; iii) no semi-tethered or in-water resisted practice during the last 3 months. To improve the reliability of the measurements, every test was individually assigned at the same time of the day and the experiment was conducted during the second macrocycle of the season (29). All participants were asked to refrain from intense exercise or any stimulant drink during the day before. All the procedures were performed in accordance with the Declaration of Helsinki with respect to human research, and the study was approved by the Institutional Review Board of the University (reference: 852).

Experimental design:

A T-test design was used to compare the differences of 2 conditioning protocols in a STRS effort. One protocol consisted of a standard swimming warm-up (SWU), which acted as control, composed of 400-m varied swim paces, including 2x50-m front crawl swim (12’5 fast/12´5 smooth); The other protocol consisted in SWU followed by a dry-land warm-up (DLWU), composed of dynamic limb stretching followed by 3 pull-over reps at 85% of the one-repetition maximum (RM) load. The STRS efforts were conducted 6 min after the experimental warm-ups with the load that maximized swimming power. This load was obtained through an aquatic incremental-load test following the same procedures reported in previous studies (12, 30). Additionally, the effort producing the maximal swimming power, was extracted to compound a new category which gathered the result achieved after several repetitions of resisted swimming (denoted INCTEST). This category was used to be compared to SWU.

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Procedure:

First, all participants visited the laboratory on 2 separate days to randomly conduct one incremental-load strength test in dry-land or in aquatic conditions. Both the in-water and the strength tests were performed on different days (72 h) to ensure that one test would not affect the other (29). The dry-land strength test was carried out to obtain the swimmer's individualized load in the pull-over CE (i.e. DLWU). Its design was based on the fundamentals of strength testing taken from the American College of Sports Medicine guidelines (31), and was adapted for study purposes based on previous research (13). Participants started the test in prone position on an inclined bench (45º from vertical), with both arms horizontally extended in front of the body, and each hand holding a handle from a pulley system installed on a Smith Machine (Jim Sports Technology S.L., Lugo, Spain) (Figure 1A). They were asked to perform a complete shoulder extension at maximal velocity, then return to the starting position in a controlled manner, remain in the starting position for 1s, and perform a second repetition. Every participant had to complete 2 reps with each load (increases of 5 kg) every 2 min. The test ended when swimmers were unable to perform a complete repetition, considering this load as the pull-over RM (38.21 ± 4.58 kg).

The aquatic incremental-load strength test was individually administered with the purpose to obtain the load that maximized swimming power. According to some authors (9, 32), swimming power expresses reliable information about swimming performance because this variable brings together the force- and velocity-related variables. The test consisted of several front crawl STRS efforts of 15-m and it was conducted in a 25-m indoor pool (water and air temperatures of 28.2 and 28.9 ºC, respectively). After performing the SWU, participants started the first effort connected to a Smith Machine by a taut rope and a waist belt through a pulley system. As every swimming effort produced the lift of the load, it was

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possible to gather the variables delivered to that load through the linear encoder (Figure 1B). This protocol was replicated (12). The swimmer adopted a frontal extended position next to the edge of the pool, with legs outstretched until the cable was fully extended, without raising the previously set load. On the tester's command, the swimming exercise started at maximum speed up to 15-m. Neither pushing-off from the wall, nor breathing, was allowed. All the efforts had time duration between 10 to 20 s. The test started with 1 kg of load (after the pulley system), and it was increased by successive 1 kg increments in order to individually obtain the execution data corresponding to the maximal swimming power load. In order to attempt total recovery, 6 min of rest were given between efforts (12, 26).

(Please insert Figure 1 near here)

Upon return for a third session, participants were randomly assigned into 2 groups. The first group underwent SWU, while the second group performed DLWU and the effects were tested after 6 min of rest in a front crawl STRS effort with the load that maximized swimming power. Finally, on a fourth day, the group order was reversed to avoid the "fatigue/learning" effect and tests were repeated.

All targeted loads, both in the aquatic and dry-land tests, were adapted and previously tested with an electronic dynamometer (WeiHeng®, Guangzhou WeiHeng Electronics Co., Ltd.). To gather the data from every STRS effort to the software application, an isoinertial dynamometer (T-Force Dynamic Measurement System, Ergotech, Murcia, Spain) was used to acquire, display, and process velocity-time data obtained from the lift of the bar of the adapted Smith Machine (12). All the aquatic registers were synchronized and visually inspected with video recordings taken from 3 cameras installed on 3 underwater portholes along the pool (Sony Video Camera, 50Hz; Sony Electronics Inc., Tokyo, Japan). One of them recorded the underwater phase to 7.5 m, the second recorded from 7.5 to 12.5 m and the third from 12.5 to 17.5 m. The three sequences were overlapped in space and time by a

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video switcher (Digital Video Switcher SE-900, Datavideo Technologies Co., Taipei, Taiwan). The first 2 arm-strokes were excluded, and the next 10 consecutive arm-strokes were selected for further analysis. The ICC between measurements was performed by two experts (intra- and inter-measurements). Ten STS efforts were digitized by 2 independent researchers with experience in processing the custom-designed routine. The intra-observer ICC ranged between 0.97 (95% CI, 0.96-0.98) and 0.98 (95%, 0.97-0.99), and the inter-observer ICC ranged from 0.96 (95% CI, 0.94-0.98) to 0.97 (95% CI, 0.95-0.99), for the stroke rate.

Variables measured

Instantaneous Velocity (V) and Acceleration (Accel) were acquired from the encoder at a sampling rate of 1000 Hz. The Force delivered to the load (F) was calculated according to Newton's second law (F=m*a) where *m* stands for the load lifted on the Smith Machine and *a* stands for the Accel signal. Data was smoothed using a fourth order Butterworth low-pass digital filter, with a cut off frequency of 10 Hz, defined according to residual error analysis versus cut-off frequency. Through the synchronization of the video recording with the encoder registering, it was possible to detect the slopes produced by every arm-stroke on the Accel signal. Therefore, every slope with values above zero was considered as a one-arm stroke (Figure 2), and the values of the variables were calculated as the means obtained on 10 arm-strokes.

(Please insert Figure 2 near here).

A trapezoidal integration regarding time was used to calculate the absolute values of impulse for each arm-stroke with a frequency of data acquisition: 1000 Hz. The impulse normalized to the load pulled (Imp_{REL}) was obtained by dividing the absolute values of impulse by the mass of the load pulled (in kg) and then this value was averaged to 10 arm-strokes (12). The swimming Power delivered to the load was calculated as the force multiplied by the velocity

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delivered and the RFD was calculated as the slope of the force-time curve (RFD=ΔForce/ΔTime) (33).

The stroke-rate (SR) was determined using a frequency measuring function for each 3 stroke cycle, divided by the time elapsed during this action (Hz), and multiplied by 60 (to obtain the rate in cycle/min). The stroke-length (SL) was determined by dividing the mean V by the mean SR (Hz).The distance covered (DC) in 10 arm-strokes was provided directly by the encoder and the time to complete 5-m (T5m) was calculated as the distance of 5-m divided by the mean V.

The Intra-cyclic Velocity Variation (IVV) was analyzed as described elsewhere (34). Where x represents the mean V; x_i represents the instantaneous V; Fi represents the acquisition frequency (1000 Hz), and n is the number of measured strokes:

$$IVV = \frac{\frac{\sqrt{\sum i(x_i - \bar{x})^2 \cdot F_i}}{n}}{\frac{\sum i x_i \cdot F_i}{n}} \cdot 100$$

Statistical Analyses:

Descriptive statistics were obtained and expressed as Mean ± SD, 95% confident intervals, relative changes (%Δ) and respective effect sizes (d). The effect sizes were categorized as follows: small if $0 \leq |d| \leq 0.5$, medium if $0.5 < |d| \leq 0.8$, and large if $|d| > 0.8$ (35). After Saphiro-Wilk testing for normality distribution, statistical differences between SWU and DLWU were determined using paired-samples T-test (ANOVA). To detect differences between the protocols, statistical significance was set at the alpha level $p \leq 0.05$. The same analysis was applied to compare results from INCTEST with results from SWU protocol. Pearson's correlation coefficient was used to determine the relation between kinetics and kinematics variables in the 3 protocols. All statistical procedures were performed using SPSS 21.0 (IBM Chicago, IL, USA).

RESULTS

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Mean, SD, 95% confident intervals, mean differences, relative changes (%Δ), P-values and effect sizes for all tested semi-tethered swimming variables are presented in Table I. P-values and effect sizes from T-test (ANOVA) are presented in Table II. Participants achieved the maximal swimming power at 4.45±0.86 kg and it corresponded to 31.18±7.98% of the maximal load.

The RFD showed to be higher after DLWU (34.52±16.55) compared to SWU (31.29±13.70; P=0.032), but no differences were observed between SWU and INCTEST. The Force, Accel, Imp$_{\text{REL}}$ and Power values were lower in DLWU compared to SWU (Table I). No differences were observed on those variables when compared SWU with INCTEST, except for Power, which showed to be higher in INCTEST (51.38±14.93 W) than obtained in SWU (49.98±15.40 W) (P=0.037).

The semi-tethered swimming Velocity, Stroke-Length, Distance covered and IVV were lower in DLWU compared to SWU (Table I), but the statistical analyses not showed differences between SWU and INCTEST. The values of Stroke-Rate (64.70±9.84 Hz) and the Time to cover 5m (5.22±0.88 s), were higher in DLWU in comparison to SWU (SR: 61.56±7.07 Hz; P=0.044) (4.23±0.57 s; P=0.003). No differences were obtained in those variables between SWU and INCTEST.

At least 3 kinetic variables obtained correlations with the kinematic variables of the STRS efforts performed. On one hand, Velocity obtained strong correlations with SR, SL and T5m in SWU, DLWU and INCTEST (Table II). On the other hand, Imp$_{\text{REL}}$ correlated with SL in the 3 protocols, with the highest value obtained after DLWU (r=0.76). At last, Power correlated with T5m (r=~-0.67–-0.81) with higher values obtained in INCTEST. Other variables such as Force obtained moderate correlations with SR and T5m in INCTEST and SWU, while IVV correlated with SR, SL and DC in the same aforementioned protocols. Finally, Accel correlated with T5m (r=-0.63) only in DLWU (Table II).

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Table I. Mean, SD, 95% confident intervals, relative changes (%Δ), P-value, and Effect Sizes of the kinetic and kinematic variables collected in semi-tethered resisted swimming (STRS). Standard warm-up (SWU); Dry-land warm-up (DLWU); Incremental test (INCTEST) (n =20).

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Variable	**SWU**	**DLWU**	**INCTEST**	**SWU vs. DLWU**			**SWU vs. INCTEST**		
				%Δ	**P-value**	**Effect size**	**%Δ**	**P-value**	**Effect size**
Force (N)	42.95 ± 10.15 (35.63 – 50.16)	41.82 ± 9.87* (34.86 – 48.99)	43.22 ± 10.13 (35.97 – 50.47)	-2.60%	0.001	-0.11	0.63%	0.052	0.02
Accel (m/s^2)	0.23 ± 0.08 (0.17 – 0.29)	0.16 ± 0.05* (0.13 – 0.20)	0.25 ± 0.08 (0.19 – 0.31)	-30.41%	0.049	-1.04	6.88%	0.117	0.25
ImpREL (N·s)	4.41 ± 1.54 (3.31 – 5.51)	3.49 ± 1.39* (2.50 – 4.49)	4.48 ± 1.58 (3.35 – 5.62)	-20.84%	0.023	-0.62	1.56%	0.078	0.04
Power (w)	49.98 ± 15.40 (38.96 – 61.00)	42.48 ± 12.95* (33.21 – 51.75)	51.38 ± 14.93* (40.70 – 62.06)	-15.01%	0.002	-0.87	2.72%	0.037	0.12
RFD (N/s)	31.29 ± 13.70 (21.49 – 41.09)	34.52 ± 16.55* (21.97 – 47.08)	31.79 ± 13.49 (22.14 – 41.44)	9.35%	0.032	0.21	1.59%	0.241	0.03
Velocity (m/s)	1.17 ± 0.12 (1.08 – 1.26)	1.01 ± 0.15* (0.90 – 1.11)	1.21 ± 0.14* (1.11 – 1.32)	-13.67%	0.001	-1.17	3.06%	0.041	0.30
SR (cyc/min)	61.56 ± 7.07 (56.64 – 66.87)	64.70 ± 9.84* (57.66 – 71.74)	61.43 ± 7.27 (56.23 – 66.64)	5.10%	0.044	0.31	-1.14%	0.204	-0.01
SL (m)	1.21 ± 0.15 (1.11 – 1.33)	0.97 ± 0.20* (0.83 – 1.12)	1.23 ± 0.16 (1.11 – 1.35)	-19.83%	<0.001	-1.35	2.34%	0.184	0.12
DC (m)	5.77 ± 0.72 (5.25 – 6.29)	4.73 ± 1.09* (3.94 – 5.51)	5.95 ± 0.88 (5.31 – 6.59)	-18.02%	<0.001	-1.12	3.13%	0.059	0.22
T5m (s)	4.23 ± 0.57 (3.82 – 4.64)	5.22 ± 0.88* (4.59 – 5.86)	4.19 ± 0.56 (3.79 – 4.60)	23.40%	0.003	1.33	-0.76%	0.087	-0.07
IVV (%)	45.98 ± 9.63 (37.36 – 54.84)	37.95 ± 7.91 (30.61 – 43.94)	44.81 ± 8.31 (36.99 – 52.42)	-17.46%	<0.001	-0.91	-2.54%	0.158	-0.13

* Significant differences (P<0.05)

Table II. Pearson's correlation coefficients of the kinetic and kinematic variables collected in semi-tethered resisted swimming. Standard Warm-Up (SWU); Dry-Land Warm-Up (DLWU); Incremental test (INCTEST); (n = 20).

		STROKE RATE		**STROKE LENGTH**		**DISTANCE COVERED**		**TIME 5M**	
		r	p	r	p	r	p	r	p
SWU	**VELOCITY**	-	-	0.821	0.004	0.710	0.020	-0.987	0.001
	FORCE	0.652	0.038	-	-	-	-	-0.610	0.046
	ACCEL	-	-	-	-	-	-	-	-
	IMP$_{REL}$	-	-	0.651	0.039	-	-	-0.709	0.027
	POWER	-	-	0.607	0.049	-	-	-0.798	0.008
	RFD	-	-	-	-	-	-	-	-
	IVV	0.615	0.050	-0.697	0.025	-0.606	0.042	-	-
DLWU	**VELOCITY**	-	-	0.743	0.014	0.742	0.014	-0.905	0.000
	FORCE	-	-	-	-	-	-	-	-
	ACCEL	-	-	-	-	-	-	-0.637	0.047
	IMP$_{REL}$	-	-	0.762	0.027	-	-	-	-
	POWER	-	-	-	-	-	-	-0.676	0.032
	RFD	-	-	-	-	-	-	-	-
	IVV	-	-	-	-	-	-	-	-
INCTEST	**VELOCITY**	-	-	0.836	0.003	0.711	0.021	-0.989	0.000
	FORCE	0.673	0.033	-	-	-	-	-0.644	0.044
	ACCEL	-	-	-	-	-	-	-	-
	IMP$_{REL}$	-	-	0.664	0.036	-	-	-0.729	0.017
	POWER	-	-	0.618	0.047	-	-	-0.810	0.005
	RFD	-	-	-	-	-	-	-	-
	IVV	0.631	0.048	-0.707	0.022	-0.656	0.039	-	-

DISCUSSION

The aim of this study was to investigate whether muscular performance could be improved after a dry-land or an aquatic warm-up in semi-tethered resisted swimming (STRS). It was hypothesized that testing swimmer kinetics variables through STRS could provide a real picture of the biological changes generated in the muscular capacity after a resistance warm-up to discern between the presence or not of performance enhancements (PAPE). The results showed an increase in RFD and stroke-rate after high-resistance pull-over repetitions; however, other variables such as velocity and distance covered showed deterioration in performance. Therefore, potentiation responses were present after the resistance warm-up, but they were not accompanied by PAPE effects.

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The simple adaptation of a linear-encoder system designed to measure performance in dry-land conditions, allowed us to also measure performance in the water (12). Considering that semi-tethered swimming allows displacement and movement velocity has been shown to be a predictor of loading intensity and strength capability in resistance training (36), our STRS protocol showed to be sensitive in obtaining valuable information about the neuromuscular changes produced on swimmers to understand how kinetic changes may affect kinematic measurements. For that reason, and while there is no possibility of acquiring another more recommended equipment (16, 28), this system could be an equally valid alternative to test swimmers despite the potential risk of altering the swimming patterns (12, 30). In fact, considering that in-water resisted procedures are usually integrated into swimming programs (10, 27), the participants would be familiar with this testing procedure.

An increase in RFD was obtained after the dry-land warm-up (Table I). However, it was not accompanied by performance enhancements. The RFD is the ability to increase force or torque as quickly as possible during a rapid voluntary contraction conducted from a low or resting level (37). It has been reported to increase after resistance training (33); to be sensitive to acute changes in neuromuscular function (38), and to be potentially governed by different physiological mechanisms such as PAP (23). However, there are several reasons to discuss why it would be inappropriate to link the effects provided by DLWU with this response-mechanism. First of all, as muscle biopsy was not conducted to verify the phoshporylation levels (23), it prevented a conclusion favoring the presence of PAP-effects. Thus, our results were based on an alternative interpretation provided by the encoder dynamic recordings (Figure 2).

Apparently, the peaks reached in Force and Velocity after SWU were not achieved after DLWU (Figure 2), which led to lower average values on this variables (Table I). At this point, it is important to note that the RFD was calculated as the slope of the Force-Time

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curve (ΔForce/ΔTime) (33). Therefore, the reduction of the slope within the stroke-cycle produced a shorter time to reach the peak, which could result in higher RFD. This fact has been reported in other studies, where apparent RFD increases did not yield performance enhancements (5, 37). In fact, considering that the differences within the stroke-cycle are dependent on the ability to overcome the resistance to generate efficient propulsion (34, 39), the significant reduction obtained in IVV after DLWU could indicate that a lower energy was transferred into the water as a consequence of the warm-up and this produced a reduction of Acceleration with an apparent increase in RFD.

The nature of a swimmer's locomotion lies in the hydrodynamic reaction forces created by the swimmer's limb movements to overcome water resistance (17). Attending to the correlations found between velocity and stroke-length in the STRS efforts (Table II), the swimmers achieving a larger arm-stroke were the ones obtaining higher velocity (r=0.73-0.84). In fact, the low values of Imp_{REL} obtained in DLWU combined with the reduction of the distance covered and the increase of the Stroke-rate seemed to support that fact, indicating that every arm-stroke was shortened and less efficient (Table I) (12, 30). Therefore, although an increase on the arm-pull speed could be a consequence of neuromuscular potentiation adaptations, it could reduce the lateral and/or sculling like movements in the arm-stroke trajectory, producing a slippery effect on the stroke cycle (9).

This conclusion is in agreement with the one already proposed by Barbosa et al. (16). The increases obtained on the arm-pull thrust reflected an acute enhancement of the neuromuscular mechanism. However, the arm-pull thrust does not essentially represent the effective propulsive force generated by the body, but the increase of the force conveyed per stroke against the water. Thus, although potentiation responses were obtained and it also produced a moderate increase in swimming velocity (~2%), it should be noted that little or

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no benefit could be obtained by increasing upper limbs performance in swimming if this is not in line with an increase of the effective propulsive impulse.

In any case, potentiation responses are always accompanied by varying fatigue manifestations (2, 40). Studies have shown that a reduced capacity to generate propulsive impulse per stroke (i.e. fatigue), decreases stroke-length and increases stroke-rate (30, 41), similar to that obtained after DLWU. Moreover, as the correlation analysis demonstrated that swimmers producing higher Velocity, Imp$_{REL}$ and Power achieved also higher Stroke-length, then such relationship between kinetics and kinematics was confirmed. Therefore, although it was nevertheless demonstrated that an uncontrolled improvement in muscular capacity could also produce a detrimental biomechanical consequence in swimming performance, it is not disregarded that the lack of PAPE effects may be a consequence of fatigue prevalence as reported in previous studies (13, 14, 27).

On the other hand, it has been debated whether the effects in power or strength provided by dry-land CEs could be transferred to the water (15). In swimming, the hand surface area and upper-body strength have shown to predict upper limb and full stroke cycle thrust, respectively (29). Concretely, the upper-body strength has been assessed in different ways both in pulling as in pushing exercises since these exercises recruits several muscles related to front crawl stroke (9-12, 29). However, the optimal intensity of the CEs is still uncertain. Some authors (6, 42), rationalized that a potentiation strategy should be maximal or near maximal intensity to increase motor unit activation (≥ 85-90% 1RM), based on the fact that the speed of force transmission through a material is influenced by the material stiffness (37). On this line, specific low-volume, high-force resistance training has been proposed as an optimal approach to transfer strength gains to swimming performance (15, 20).

However, a very heavy resistance set may temporarily result in some increased stiffness of the musculo-tendinous unit and specifically the series elastic component (SEC) than what

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would be optimal considering the lighter resistance to be overcome (43). According to Baker (8), the use of very heavy resistances in contrast loading for the upper body may not be as effective as for the lower body, possibly due to the smaller muscle mass involved. Moreover, since the velocities reached on the CE were clearly slow, the required innervated fibers may not be appropriate, creating an erroneous stimulation pattern (8, 24). This motor pattern interference has been identified in previous literature as "perseveration", since the motor gross pattern of a task (e.g., cycling) perseveres, while a subsequent task of a different modality (e.g., running) is commenced (44, 45). Therefore, at this point it is worth mentioning that the dry-land CE was not included in either SWU or INCTEST.

The maximal swimming power during INCTEST was achieved at 4.45±0.86 kg, which means that at least 3 to 5 STRS efforts were performed by every participant before establishing such category. However, the results did not seem to be affected by fatigue but by PAPE effects (26). According to some authors, temperature changes could explain velocity and power-dependent effects in muscle mechanisms (4, 46, 47). Therefore, it is not surprising that the high volume of work of INCTEST produced a reasonable increase in muscle temperature. However, such argument could make questionable the deterioration encountered in DWLU, given that this protocol also received a considerable amount of work (i.e. SWU followed by DLWU). Possibly, some tension sensitive receptors such as the Golgi tendon organ could account for a consequent change in power output reducing their negative inhibitory feedback after a moderate increase in resistance (8). These neurological adaptations may have temporarily resulted in a favorable increase in SEC stiffness in the ensuing STRS efforts that may have triggered PAPE responses (48-50).

At last, another possible explanation may reside in the rest time given between efforts (12, 13, 26). Although the deviating time course of performance enhancement is an individually regulated response that depends on the training experience and the nature of the participants

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muscle fiber composition (24, 40), an inappropriate time of rest would diminish or mask the effects of PAPE (13, 27). Nevertheless, some mechanisms such as the vascular bed dilation/blood muscle perfusion and the increased muscle temperature are only possible after several minutes (4 to 10 min) (4, 5, 47). Therefore, the rest period chosen (6 min), was presumably adequate to allow performance enhancements in INCTEST. In such case, the effort displaying the maximal power gathered performance enhancements prompted by the efforts that preceded it (i.e. at 10-30% of the maximal load).

This study presented some limitations, as the STRS encoder recordings may not just be from the arm action throughout the underwater stroke, but also from the leg action. In any case, according to a previous research (15), the majority of propulsive forces in swimming are produced from the upper body, with strong correlations between upper body strength and sprint performance. Future research should provide more information about this issue and continue to attempt CEs (both in aquatic and in dry land conditions) to transfer the effects of PAPE to cyclic sports such as swimming. The inclusion of differentiated arm movements, rotation of the body, or low loaded conditioning exercises may allow faster movements and, therefore, better adaptations.

CONCLUSIONS

This study showed RFD potentiation responses on swimmers after a dry-land resistance warm-up. However, they did not improve swimming performance, possibly due to alterations in the biomechanics of the stroke. In any case, it seems that swimmers may benefit more from submaximal prolonged conditioning activities conducted in the water to develop high Power and propulsive Impulse, due to adaptive changes of the neuromuscular system. Specifically, attaining a high propulsive Impulse could have a positive influence in other kinematic variable such as Stroke-Length, which is important to achieve a good race result.

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NOTES

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TABLES

Table I. Mean, SD, 95% confident intervals, relative changes (%Δ), P-value, and Effect Sizes of the kinetic and kinematic variables collected in semi-tethered resisted swimming (STRS). Standard warm-up (SWU); Dry-land warm-up (DLWU); Incremental test (INCTEST) (n =20).

Table II. Pearson's correlation coefficients of the kinetic and kinematic variables collected in semi-tethered resisted swimming. ~~(STRS) with the maximal swimming power load (MSPL).~~ Standard Warm-Up (SWU); Dry-Land Warm-Up (DLWU); Incremental test (INCTEST); (n = 20).

TITLES OF FIGURES

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

Figure 2. — One case example that demonstrates the means by which PAPE may affect performance of the same swimmer in DLWU compared to SWU.

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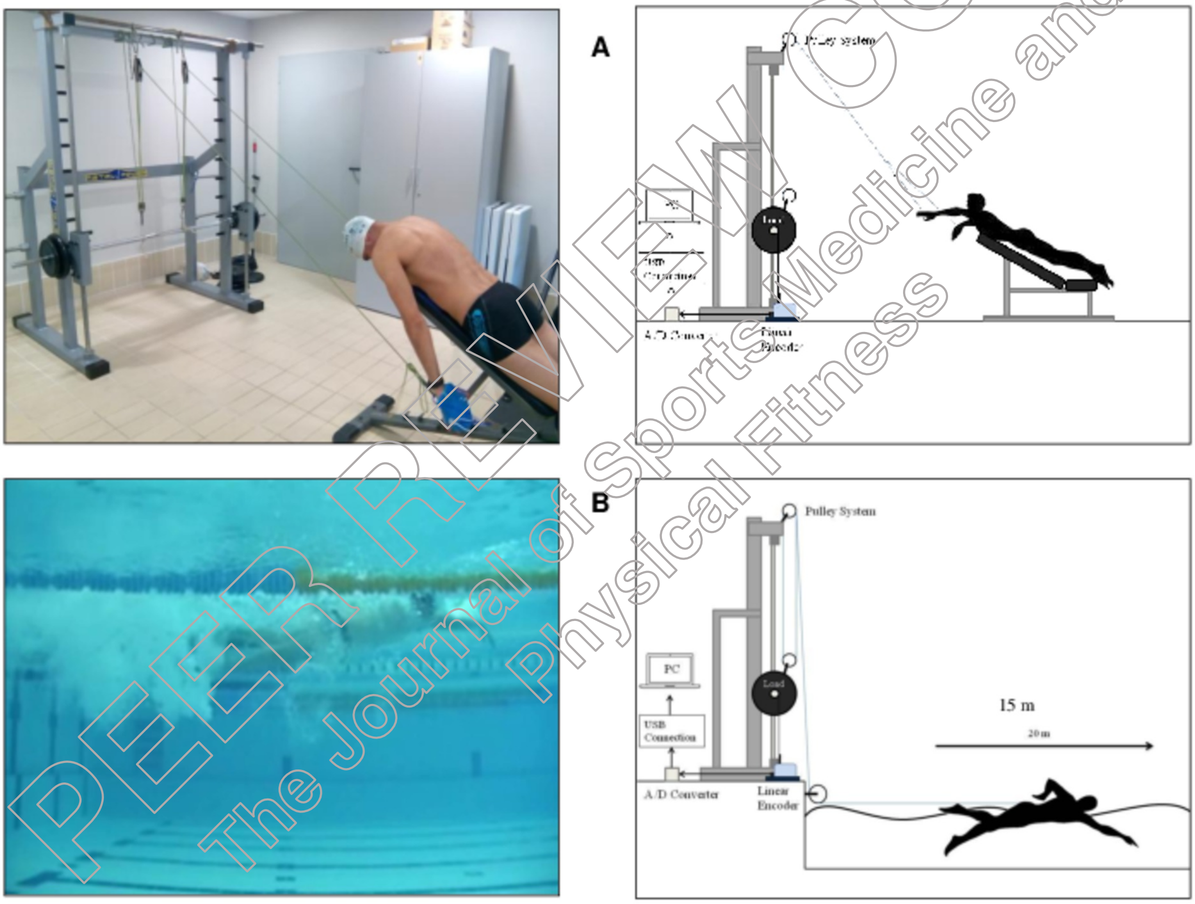

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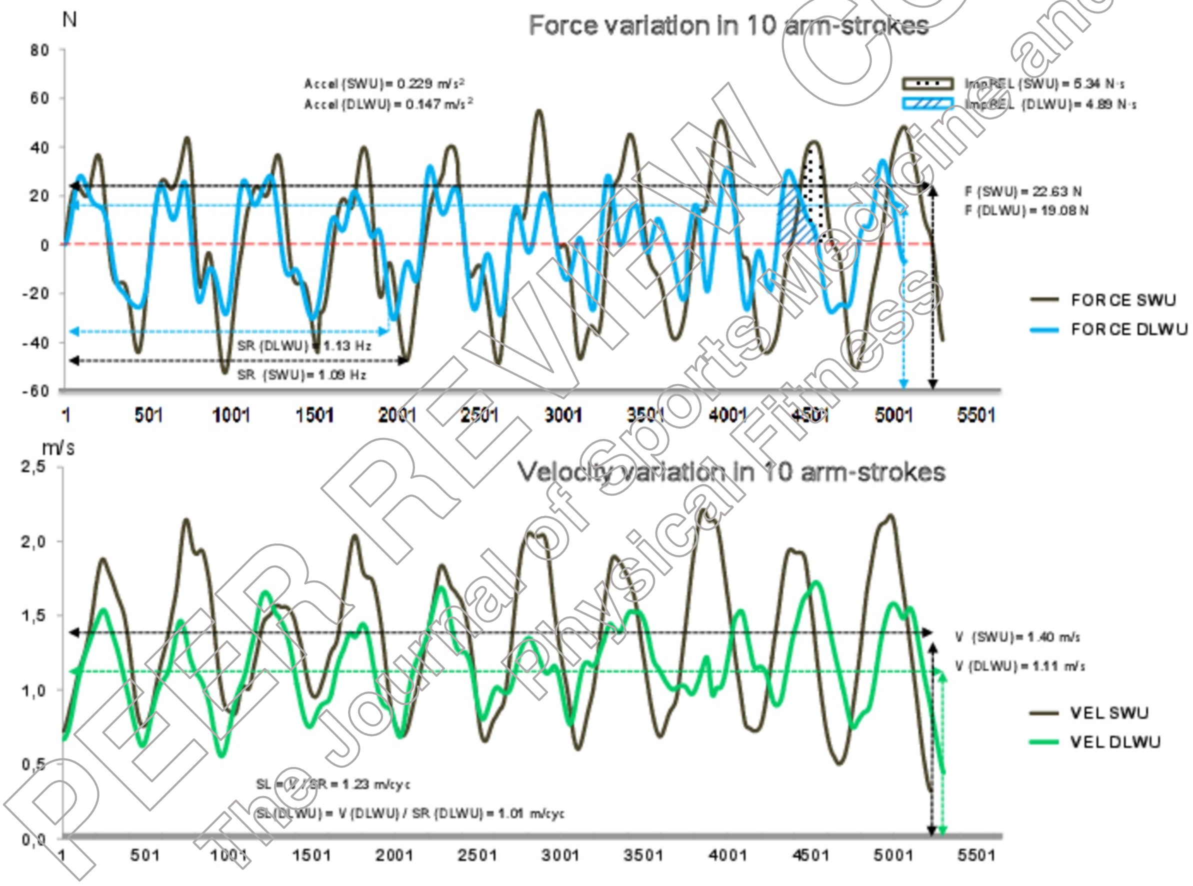

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