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Abstract: This study aimed to investigate the relationship between the load-velocity profile and sprint swimming performance and kinematics; explore the inter-relationships of the load-velocity profile variables and blood lactate concentration[La-] and dry-land strength(pull-ups); and examine sex-based differences. Twenty-seven swimmers (15 males: 19.2±3.7yrs; 50m front-crawl 550±70 World Aquatics points; twelve females: 17.7±2.4yrs; 50m front-crawl 552±63 World Aquatics points) underwent a 50 m front-crawl all-out swim test, a load-velocity profile test, and a pull-up test. Theoretical maximum velocity (V0) was associated with sprint swimming performance ($r>0.863$, $p<0.001$), but not the theoretical maximum load (L0) or the Slope ($p>0.05$) for both sexes. Association between kinematics during the load-velocity profile test and free swimming weakened as the load increased, with the correlation coefficient (r) decreasing from 0.929 to 0.403. V0 and L0 were primarily associated in both sexes with the first($r>0.950$, $p<0.001$) and last ($r>0.849$, $p<0.001$) semi-tethered trials, respectively. Only in females[La-] was associated with L0 and Slope ($r>0.573$, $p<0.05$). Males exhibited greater values than females in all the assessed variables($p<0.05$) except for stroke rate and [La-]. The load-velocity profile is a valuable tool for assessing performance in both sexes. Kinematic parameters were related between semi-tethered and free swimming, however association diminished with increasing load.

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Abstract

This study aimed to investigate the relationship between the load-velocity profile and sprint swimming performance and kinematics; explore the inter-relationships of the load-velocity profile variables and blood lactate concentration [La$^-$] and dry-land strength (pull-ups); and examine sex-based differences. Twenty-seven swimmers (15 males: 19.2 ± 3.7 yrs; 50m front-crawl 550 ± 70 World Aquatics points; twelve females: 17.7 ± 2.4 yrs; 50m front-crawl 552 ± 63 World Aquatics points) underwent a 50 m front-crawl all-out swim test, a load-velocity profile test, and a pull-up test. Theoretical maximum velocity (V_0) was associated with sprint swimming performance ($r \geq 0.863$, $p<0.001$), but not the theoretical maximum load (L_0) or the Slope ($p>0.05$) for both sexes. Association between kinematics during the load-velocity profile test and free swimming weakened as the load increased, with the correlation coefficient (r) decreasing from 0.929 to 0.403. V_0 and L_0 were primarily associated in both sexes with the first ($r \geq 0.950$, $p<0.001$) and last ($r \geq 0.849$, $p<0.001$) semi-tethered trials, respectively. Only in females [La$^-$] was associated with L_0 and Slope ($r \geq 0.573$, $p<0.05$). Males exhibited greater values than females in all the assessed variables ($p<0.05$) except for stroke rate and [La$^-$]. The load-velocity profile is a valuable tool for assessing performance in both sexes. Kinematic parameters were related between semi-tethered and free swimming, however association diminished with increasing load.

Keywords: semi-tethered, sex characteristics, in-water forces, exercise test, sprint.

Fundings

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Introduction

The athlete development is a multifactorial process aimed at enhancing biomechanical, physiological, or/and psychological factors to improve overall performance [1,2]. For instance, in sprint swimming, factors such as muscular force production during stroking, swimming technique, and anaerobic/aerobic energy production are important key performance indicators [3,4]. However, these factors can be measured using a wide variety of methods and protocols, making it challenging to establish standardized assessments.

Initially used to determine the load-velocity profile during land-based 1-repetition maximum strength tests way [5], load-velocity profiling has soon been applied to swimming. First feasible equipment to conduct swim-specific load-velocity profiling was commercially available since the 2015s. Using those portable robots, load-velocity profiling has become increasingly popular in the aquatic environment [6–9], and studies were conducted to determine the association of load-velocity profile with sprint performance in all four competitive swimming strokes [6–9]. The results have led to the proposal of this method as a practical tool for monitoring changes in swimmers' performance [6–10]. However, to our knowledge, the association between the kinematics during the load-velocity profile and the kinematics during free swimming has not been explored.

The load-velocity profile is created via semi-tethered swimming, in which the swimmer propels themselves forward while being subjected to an external load. The velocity achieved at each specific load is then plotted against each other following a linear relationship ($r^2 \geq 0.98$)[8,10]. From the stablished profile underlines three specific parameters: the maximum velocity at zero load (V_0), the maximum load at zero velocity (L_0) and the steepness of the regression line (Slope). Together, these parameters provide insights into an athlete's maximum velocity, ability to produce propulsive forces, and the ability to minimize resistive forces, which are associated with performance [7,8,10,11]. Despite current knowledge, the connections between the three mentioned parameters and the velocities and physiological responses elicited during each load displacement remain unclear, yet understanding these relationships are essential for better interpreting the training-induced changes. Additionally, although the load-velocity profile is used to assess neuromuscular capacities during swimming, the relationship between the aforementioned parameters and dry-land strength capabilities remains to be investigated, which could offer valuable insights for enhancing the swimmers' development.

Females have historically been underrepresented in sport and exercise-related research [12], particularly, the load-velocity profile has primarily been studied in male swimmers [7,10]. To the best of our knowledge, there are no studies exploring the relationship between the load-velocity profile and sprint swimming performance in females, which underscores the need to examine these associations and the differences to males. Therefore, in the light of the above, the objective of this study was three-fold: 1) to investigate the relationship between the load-velocity profile and sprint swimming performance and kinematic variables 2) to explore the inter-relationships of the load-velocity profile variables and [La$^-$] and dry-land strength; and 3) to examine possible sex-based differences. It was hypothesized that a strong positive association exists between performance and kinematics during the load-velocity profile and performance and kinematics during sprint swimming (e.g., V_0 would be associated with sprint swimming performance, stroke rate during the semi-tethered load would be associated with the free swimming stroke rate). The V_0 and L_0 would be influenced differently by the different loads (i.e., V_0 would be associated with the performance during the light loads, while L_0 would be associated with the performance during the heavy loads). Moreover, it was expected an association between the load-velocity parameters and [La$^-$] as well as between load-velocity parameters and dry-land strength. Generally, across all the assessed variables, higher values were expected in males compared to females.

Methods

Design

This cross-sectional study was conducted on a single day due to swimmers' availability and given the large rest periods between trials that allowed swimmers for complete recovery. To ensure an optimal physical condition and align with competition calendar and the general training regime, the testing was conducted during the tapering phase for the final peak performance, hence the week before the most important competition of the season. All tests were conducted for each swimmer on a single day. In addition, the athletes were instructed to refrain from strenuous exercise and maintain similar dietary habits on the day before and the day of the tests. To align the data collection for the present study with the training schedule of the swimmers, testings were conducted on Monday mornings after a complete rest day on Sunday. Finally, during the test session, there was verbal encouragement for participants to exert maximum effort. All testing was carried out in a 25m swimming pool (25m length × 16.5m width × 2.07 m depth) (water temperature: 27.6 °C; air temperature: 28.8 °C; and relative humidity: 51%).

Participants

Twenty-seven swimmers, fifteen males (19.2 ± 3.7 years, 175.3 ± 7.0 cm of height, 71.7 ± 6.9 kg of body mass, 23.2 ± 1.1 kg/m² of body mass index [BMI], and 50-m front-crawl 550 ± 70 World Aquatics points, level 4 [13]) and twelve females (17.7 ± 2.4 years, 166.1 ± 6.7 cm of height, 58.3 ± 5.2 kg of body mass, 21.1 ± 1.2 kg/m² of BMI, and 50-m front-crawl 552 ± 63 World Aquatics points, level 4 [13]) who compete mainly in 50 and 100 m events. To be included, swimmers were required to have at least six years of regional and/or national competition experience. All participants trained in at least six water and four dryland training sessions per week. Before signing an informed written consent form, the protocol was explained to the swimmers and the parents of those participants under 18 years of age. The study was conducted according to the Code of Ethics of the World Medical Association (Declaration of Helsinki) and the protocol was approved by the University of Anonymity ethics committee (CODE: Anonymity).

Methodology

At the swimmers' arrival to the facilities, anthropometric variables were taken following standardized techniques adopted by the International Society for the Advancement of Kinanthropometry (ISAK). Height and body mass were evaluated using a stadiometer and body scale (Seca 799, Hamburg, Germany) by an ISAK Level 2 accredited researcher. The BMI was computed as: body mass (kg)·height (m)$^{-2}$.

After assessment of the anthropometrics, the swimmers performed their standardized dry-land warm-up which mainly consisted of: joint mobility, dynamic stretching, and elastic band pre-activation exercises. In addition, 2-3 submaximal pull-ups (i.e., performed at a controlled, non-maximal velocity) were performed as part of the specific warm-up. Afterwards, five times one pull-up with two min rest in between were performed as follows: hang from the bar with a pronated grip and fully extended elbows; and execute the pull-up at the maximum intended velocity upon the researcher's signal. Any trial in which horizontal movement was observed or the swimmer's chin did not reach the bar was excluded from further analysis, and an additional trial was requested [14]. To increase the reliability of the measurement, the pull-up movement was examined by the same researcher. The performance was measured using an isoinertial dynamometer (T- Force Dynamic Measurement System, Ergotech, Murcia, Spain) attached to the subjects' hips with a harness. The trials with the highest and lowest mean velocity values of the propulsive phase (net Force > 0 [15]) were excluded, and the average of the remaining three trials was calculated [16]. Average propulsive velocity, force, and power were obtained.

Subsequently, the participants performed an in-water warm-up comprising 200 m (100 m usual breathing and 100 m breathing every five strokes), 2 × 100 m (2 × [25 m flutter + 25 m increased stroke length]) on 1:50 min, 6 × 50 m (2 × 50 m drill; 2 × 50 m building up swimming speed; and 2 × [25 m race pace + 25 m easy]) on 1:00 min and 100 m easy swim. The warm-up was adapted from previous literature to meet the swimmers' requirements for their in-water warm-up routine before competitions [17]. Ten min after completing the in-water warm-up, the swimmers performed a load-velocity profile test, which consisted of three 20 m front-crawl semi-tethered swims with a push-off start (without undulatory underwater swimming) at maximal effort followed by 6 min of total recovery [10]. The loads were 1, 5 and 7 kg and 1, 3 and 5 kg for males and females, respectively. These loads were adapted from previous research (males: 1, 5 and 9 kg; females: 1, 3 and 5 kg)[10] as two males struggled with the 9 kg load during a pilot-test [11]. The external load was applied using the 1080 Sprint 2, a robotic resistance device (1080 Motion, Lidingö, Sweden), previously used for load-velocity profile testing as it allows to measure swimming velocity and force simultaneously at a recording frequency of 200 Hz. During the measurement, the device was positioned and secured on the pool wall with the origin of the cord at 0.63 m above the water surface. The cord was attached to the back of the swimmers' waists using the manufacturer's belt. This test has shown an excellent agreement (ICC ≥ 0.902) for all variables [10].

The data was downloaded from the 1080 Motion web app (https://webapp.1080motion.com) and further analyses were carried out in Python (V3.11.5) using a customized script. Since the device was placed at 0.63 m above the water level. To prevent interference with the swimmers' kicking motion, the subsequent correction was applied to attain the horizontal component of the velocity [7]:

$$V_H = V \times \cos[\, sin^{-1}\left(\frac{0.63}{L_C}\right)] \quad \text{(Eq. 1)}$$

V and V_H denote the average velocities before and after correction, respectively. The value 0.63 refers to the height (m) of the device (origin of the cord) above the water level, while LC is the length (m) of the cord from the device to the swimmer.

The average swimming velocity (V_{LVP}) was calculated in the 10-15m section to ensure that all the swimmers were analyzed in the same section, thus controlling for push-off effect, fatigue, and stroke adjustments after resurfacing [18]. A linear regression line was established for each load-velocity profile by plotting the calculated average V_H against the respective external load [7,8,10,18]. The theoretical maximal values of V_H (V_0) and load (L_0) were calculated using the intercept of the regression line with the vertical and horizontal axes, respectively. The V_0 represents the theoretical maximal velocity an athlete can swim freely without loads and L_0 represents the theoretical maximal load that a swimmer can pull without being towed backward. The Slope was computed as Slope = – V_0/L_0 and represents the steepness of the linear regression line for the load-velocity relationship. A mean value of 0.99 was obtained for the calculated coefficient of determination (r^2). In addition, stroke rate (SR), stroke length (SL) and stroke index (SI) were measured in each condition.

The [La⁻] was measured during the load-velocity profile test. Capillary blood samples (25 μL) were collected from the same fingertip 1 min before the first semi-tethered trial and immediately after each effort. Furthermore, after the third trial [La⁻] was analyzed at minute 1 and every 2 minutes until the peak was reached. The samples were analyzed using Lactate Pro 2 analyzer (Arkray Inc., Kyoto, Japan). Finally, swimmers rested for 10 minutes before performing a 50 m all-out front-crawl swim with an in-water start. All the semi-tethered trials and 50 m all-out were recorded in digital video with a Sony FDR-AX53 (Sony Electronics Inc., Tokio, Japan) at 100 Hz sampling rate. The camera was positioned in the stands of the pool at a water height of ~7m and at a distance of~20 m from the swimmer. All videos were analyzed by an expert evaluator using custom in-house software designed for race analysis in competitive swimming (intraclass correlation coefficient ≥ 0.975) following previously published methods [19]. The 50 m time, 25 m split times, clean swimming speed, SR, SL and SI were collected following previously established methods in the literature [20].

Statistical analysis

The normality of all the variables was tested using Shapiro-Wilk's test. Mean and standard deviation (SD) for descriptive analysis were obtained and reported for all measured variables. Pearson product-moment correlation coefficients (r) were used to verify the relationship between the and load-velocity profile related variables, sprint swimming performance, and kinematics variables. Variables that were not normally distributed were analyzed using Spearman's correlation coefficients (rho). The threshold values denoting small, moderate, large, very large, and extremely large correlations were defined as 0.1, 0.3, 0.5, 0.7 and 0.9, respectively[21]. Independent sample t-test was used to compare males and females. Non-parametric independent sample t-test (Mann–Whitney U test) was performed in the non-normally distributed variables. Since identical results were obtained for both parametric and non-parametric tests, only the

181 parametric independent sample t-test data were reported [22]. The relative change between sexes
182 performance was calculated as shown in Eq 2. Cohen's (d) effect sizes were calculated for the
183 pairwise comparisons and categorized as small if $0 \leq |d| \leq 0.5$, medium if $0.5 < |d| \leq 0.8$ and large
184 if $|d| > 0.8$[23]. All statistical procedures were performed using Jamovi software package version
185 2.3.28.0 (Jamovi Project 2022, retrieved from https://www.jamovi.org) with the level of statistical
186 significance set at 0.05. Subsequently, a post hoc power analysis was conducted for the
187 correlations and parametric independent samples t-test using G*Power version 3.1.9.7
188 (Universität Düsseldorf, NRW, Germany)[24].

$$Relative\ change\ (\%\Delta) = \frac{Males'\ performance - females' performance}{females' performance} \times 100 \quad \text{(Eq. 2)}$$

189

190 **Results**

191 Table 1 presents sex-based mean ± SD differences for load-velocity-related variables and sprint
192 swimming performance along with corresponding p-values, 95% confidence intervals, relative
193 changes (%Δ), and effect sizes. Differences between sexes with a range of d = [1.03-2.89],
194 acquired a statistical power spanning from [0.83-0.99]. While he V_0 and 50 m performance were
195 largely associated in both sexes ($r \geq 0.850$, $p < 0.001$), neither L_0 nor slope were related to
196 performance ($p > 0.05$) (Figure 1). The V_0 was associated with the V_{LVP} in each trial, although
197 this association decreased as the load increased. On the other hand, L_0 showed the opposite
198 behavior, with the association increasing as the load increased. No association was observed
199 between dry-land strength and load-velocity profile variables or 50 m all-out performance ($p >$
200 0.05) (Figure 1). Figure 2 illustrates the kinematics association between tests, being especially
201 high between the free swimming and the light load. Finally, correlations between variables
202 derived from the load-velocity profile and the [La^-] from the various time points are presented in
203 Figure 3, with a lack of correlations in males ($p > 0.05$) and moderate/large association between
204 [La^-] and L_0 and Slope These correlations with a range of r/rho = [|0.535-0.972|] for males and

r/rho = [|0.570-0.957|] for females achieved statistical power ranging from [0.70-0.99] and [0.66-0.99], for males and females, respectively.

As hypothesized, a strong association was observed between V_0 and 50 m performance, as well as between kinematic variables during both tests, with these relationships being particularly pronounced in females. The main findings were that the V_0 and L_0 were differentially influenced by Slope and V_{LVP}. Contrary to the expectations, no association were found between performance metrics and dry-land strength. Additionally, only females showed large associations between load-velocity parameters and [La^-]. While similar [La^-] an SR were similar in both sexes, males exhibited higher values than females across all assessed variables.

[Please insert Table 1 near here]

[Please insert Figures 1, 2, and 3 near here]

Discussion

The aim of the present study was three-fold: 1) to investigate the relationship between the load-velocity profile (i.e., V_0, L_0 and Slope) and sprint swimming performance and kinematic variables 2) to explore the inter-relationships of the load-velocity profile variables and [La^-] and dry-land strength; and 3) to examine possible sex-based differences. As hypothesized, a strong association was observed between V_0 and 50 m performance, as well as between kinematic variables during both tests, with these relationships being particularly pronounced in females. The main findings were that the V_0 and L_0 were differentially influenced by Slope and V_{LVP}, being V_0 primarily associated with velocity at light loads, while L_0 was more closely related to velocity at heavy loads and the Slope. Contrary to the expectations, no association were found between performance metrics and pull up average propulsive velocity, force or power. Additionally, only females showed large associations between load-velocity parameters and [La$^-$]. While similar [La$^-$] an SR were similar in both sexes, males exhibited higher values than females across all assessed variables.

Since the V_0 represents the theoretical maximal velocity an athlete can swim freely without loads, it is logical that V_0 is largely associated to sprint swimming performance [7]. Also in previous results, the L_0 only showed moderate association with sprint front crawl performance [7]. While the L_0 represents the swimmer's strength capabilities, these must be applied effectively in the water [25]. Hence, high strength capabilities will not be directly translated into higher swimming velocity, unless this higher manifestation is properly transferred to the water [4]. Hence, the lack of correlation observed in the current study might be related to technical aspects [4]. On the other hand, in line with previous research, the Slope was not associated to sprint front crawl performance [7]. This parameter has been recently proposed as an indicator of active drag [11], however, it cannot fully explain performance alone, given the crucial role of propulsive forces in the final propulsion. Thus, its lack of direct correlation with sprint performance does not detract from its usefulness, but rather provides complementary information. For instance, an improvement in V_0 without a corresponding increase in L_0 would result in a steeper slope, indicating greater efficiency in reducing drag. This insight can help interpret changes in performance beyond strength measures alone, obtaining all the parameters in a single test and providing a deeper understanding of training-induced effects, which might allow a more individualized approach to future training programs.

The external load moved during semi-tethered swimming evokes changes on swimming kinematics [26]. These alterations are known to become greater with increasing load [26]. However, individual variations in response are also evident, as the correlation between kinematic variables decreases with increasing load (see Figure 2). This suggests that kinematic changes elicited by different loads vary across swimmers, which may also influence the training adaptations. These results are likely affected by the fact that absolute loads (i.e., males: 1,5 and 7 kg; females:1,3 and 5 kg) were used and similar results may not be evidenced when employing relative loads. While previous research has employed relative loads for analysis, these loads were adjusted based on body mass and may not be as accurate as adjusting them relative to the maximum load (i.e., L_0). Therefore, future research should explore the impact of loads relative to the L_0 for the assessment of load-velocity relationships and kinematic responses.

The V_0 was associated with the V_{LVP} across all three loads, although the strength of this association weakened as the load increased. Conversely, L_0 displayed the opposite pattern, with its association with V_{LVP} strengthening as the load increased. Since velocity and strength are mediated by different neuromuscular mechanics [27], these results indicate that increasing the velocity while displacing heavy loads may not necessarily transfer into higher free-swimming speed. The observed associations emphasize the importance of focusing on velocity development at lower loads rather than prioritizing velocity increases at higher loads. Indeed, when performing resisted swim training, the group with lower mean intensities (loads) showed better results than those with higher mean intensities [28]. Although in the aforementioned study no performance improvements were observed, due to other influencing factors, its findings align with those of the present study. This raises the question of whether resisted swimming training should be performed with high or low loads, considering not only the association with V_0 but also due to the different conditions, i.e., changes in drag experienced or kinematics such as SR, SL or relative duration of the separate phases of the stroke [11,26,29]. The slope showed a similar trend to L_0, which can be attributed to the strong association between these parameters. This relationship suggests that the slope is more sensitive to changes in L_0 than in V_0 [7,10] or conversely, changes in the slope may induce more significant changes in L_0 than in V_0.

Lactate plays a key role in sprint exercises, making it one of the most commonly measured metrics in sports performance analysis [4,30]. However, up to date, it had not been measured (or at least reported in the literature) during the load-velocity profile. As swimmers performed the tethered sprints, the [La^-] raised over the three consecutive trials (Table 1). This higher value could be attributed to the longer duration of exertion as the load increased. In addition, despite implementing a full recovery period between trials (i.e., 6 min)[10], it is also possible that [La⁻] still remained elevated at the beginning of the subsequent trials. With regards to the association with the load-velocity profile parameters, different outcomes were observed between sexes, as males evidenced lack of association, with large association between basal levels and V_0 and Slope, while females showed large to very large association between all [La⁻] measurements and L_0 and Slope. The females' results are in accordance with previous research, which found very large association between maximal lactate accumulation rate during a 20 m all-out and L_0 and Slope[3]. This might indicate the connection between glycolytic power and the ability to exert force in the water [3]. The fact that [La⁻] reflects the balance between production and clearance may explain the varying associations observed [31]. Two swimmers might display the same lactate values, yet likely differ in aerobic and anaerobic capacities. Given the greater heterogeneity among male participants (higher SD than females in almost all variables, Table 1), differences in aerobic capacity could have led to cases like the aforementioned described, contributing to the lack of correlation. Future studies should consider measuring [La⁻] alongside a detailed assessment of aerobic capacity and lactate production rate to better understand these relationships [31].

The pull-up is one of the most common upper body exercises in swimming [14,16], to strengthen the latissimus dorsi, one of the main muscles activated during swimming [32]. However, the expected association between pull-up average propulsive force, velocity or power and V_0 was not evidenced, neither in males nor females. In this sense, the lack of association between dry-land strength and sprint swimming performance may be attributed to technical skills, as dry-land strength is not always directly related to performance [4], and its influence is often mediated by other factors that indirectly affect performance [2]. For instance, a study focusing on the importance of anthropometry in swimming velocity observed that the longer the upper limbs the greater the force required to apply (greater moment arm)[33]. Hence, two swimmers with similar strength will not transfer it equally to the water if having different dimensions of the upper limbs. On the other hand, the non-correlation with L_0 may be explained by the bodyweight nature of the pull-up exercise; a different outcome might be observed when testing maximum repetitions of an exercise that involves the latissimus dorsi (e.g., lat-pull-down or prone bench pull)[34]. These results are inconclusive and further research is needed to better understand the impact of dryland strength in the load-velocity profile.

With the exception of [La^-], both sexes showed similar patterns in regard to associations between load-velocity and the other parameters. Similar behavior for males and females were also reported regarding differences in dry-land force-velocity characteristics [35]. Hence, it can be interpreted that the development of the load-velocity profile parameters is similar between sexes, indicating that no specific adaptations beyond the absolute load should be considered. With regards to the magnitude of the variables, males tended to exhibit higher values compared to females, a trend observed in previous studies [14,36]. These differences have been widely documented in the past and attributed to the differences in anthropometry, muscle mass and strength levels [37,38]. Nevertheless, similar [La^-] and SR values were observed in both sexes. The [La^-] results might be influenced by the higher exertion time, as both sexes cover the same distance, females were slower and hence had greater effort time. In regard to SR, the difference in speed between males and females primarily results in differences in SL, while SR remains similar [39], which are in accordance to our results. Finally, it is important to mention, that the second and third load employed were different between sexes (higher for males) and despite this difference, males exhibited higher values than females. Therefore, at equal absolute loads, the difference is likely to be bigger, but it remains unclear whether the same pattern would be observed with relative loads.

Conclusion

This study highlights the important role of V_0 which is very largely associated with sprint swimming performance, but not L_0 and slope. Kinematic parameters during the load-velocity profile test are related to free swimming kinematics; however, this association weakened with increasing load added to the semi-tethered swimming, underscoring the variable impact of different loads on swimmers. The V_0 and L_0 are primarily correlated to the first and last semi-tethered trials, respectively, suggesting a low interchangeable response between the two parameters. Additionally, [La-] might reflect the connection between glycolytic power and the ability to exert force in the water, at least in females. There is not direct association between the load-velocity profile and pull-up performance. While the behavior of the load-velocity profile was consistent between sexes, males exhibited greater values than females.

Declarations of interest: none

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Tables and figure captions

Table 1. Sex-based mean differences. The Mean ± standard deviation (SD) and 95% confidence intervals (CI) values are presented along with their corresponding p-values, mean differences and 95% confidence intervals (CI), relative changes (%Δ) and effect sizes..

Figure 1. Correlations between load-velocity profile variables, 50 m all-out performance and dry-land strength. Males (n = 15) in top corner and females (n = 12) in botton corner.

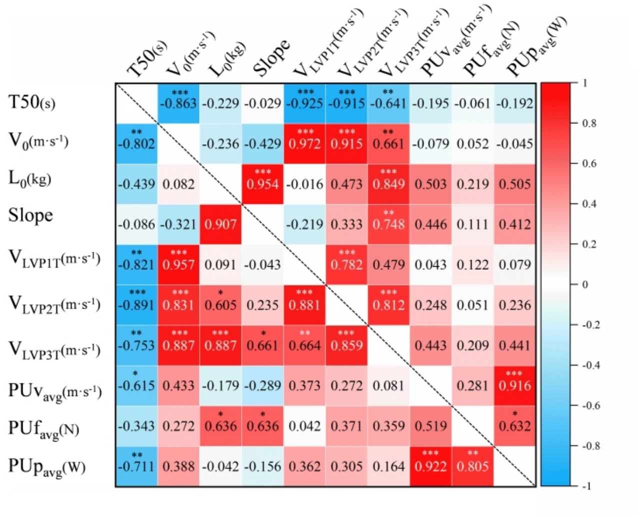
T50: 50m swimming time, V_0: maximum velocity at zero load; L_0: maximum load at zero velocity; Slope: steepness of the linear regression line for the load-velocity relationship; V_{LVP1T}, V_{LVP2T}, V_{LVP3T}: swim velocity during the first, second and third load velocity profile trial, respectively; PUv_{avg}: average propulsive velocity; PUf_{avg}: average propulsive force; PUp_{avg}: average propulsive power. *, ** and ***: $p < 0.05$, 0.01 and 0.001, respectively.

Figure 2. Kinematic correlations between tests (n= 15 males and 12 females).

Stroke rate, stroke length and stroke index values from Trial 1, Trial 2 and Trial 3, correlated with the stroke rate (SR_{50}), stroke length (SL_{50}) and stroke index (SI_{50}) values recorded during the 50m free swimming test. *, ** and ***: $p < 0.05$, 0.01 and 0.001, respectively.

Figure 3. Correlations between load-velocity profile variables and lactate (n= 15 males and 12 females).

[La^-]: blood lactate concentration; basal: basal blood lactate concentration; peak: peak blood lactate concentration; net: blood lactate concentration difference between the [La^-] peak before and basal values; 1T, 2T, 3T: first, second and third trial, respectively; V_0: maximum velocity at zero load; L_0: maximum load at zero velocity; Slope: steepness of the linear regression line for the load-velocity relationship. * and **: $p < 0.05$ and 0.01, respectively.



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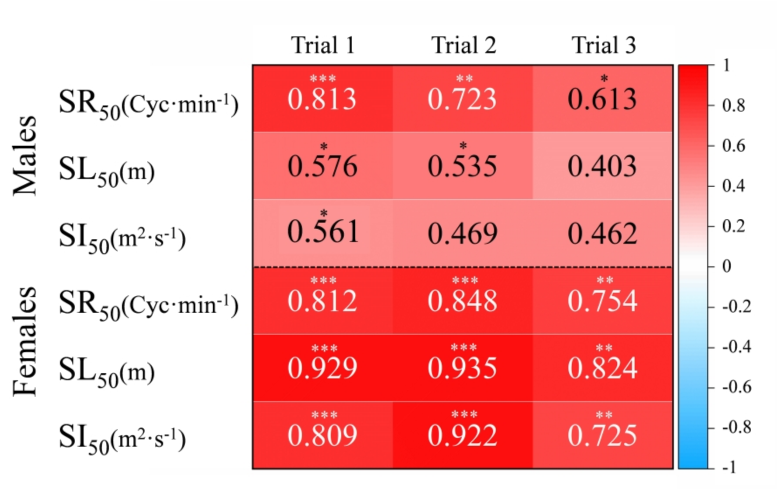

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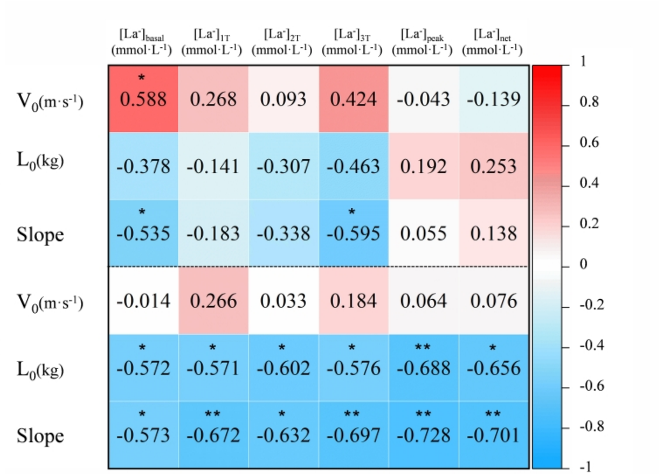

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Table 1. Sex-based mean differences. The Mean ± standard deviation (SD) and 95% confidence intervals (CI) values are presented along with their corresponding p-values, mean differences and 95% confidence intervals (CI), relative changes (%Δ), and effect sizes.

	Variable	Males (95%CI)	Females (95%CI)	Difference (95%CI); Δ%	*p*-value	Effect size (*d*)
Load- velocity profile	V_0 (m·s^{-1})	1.79 ± 0.12 (1.72 to 1.86)	1.61 ± 0.10 (1.55 to 1.68)	0.2 (0.1 to 0.3); 10.9 %	< 0.001	1.59, large
	L_0 (kg)	18.43 ± 3.29 (16.61 to 20.25)	10.82 ± 1.43 (9.91 to 11.73)	7.6 (5.5 to 9.7); 70.3 %	< 0.001	2.89, large
	Slope	-0.10 ± 0.02 (-0.11 to -0.09)	-0.15 ± 0.02 (-0.17 to -0.14)	0.1 (0 to 0.1); -33.6 %	< 0.001	2.30, large
	V_{LVP1T} (m·s^{-1})	1.68 ± 0.11 (1.62 to 1.74)	1.45 ± 0.09 (1.39 to 1.51)	0.2 (0.1 to 0.3); 15.8 %	< 0.001	2.25, large
	$V_{LVP\,2T}$ (m·s^{-1})	1.30 ± 0.13 (1.22 to 1.38)	1.18 ± 0.10 (1.12 to 1.24)	0.1 (0 to 0.2); 10.4 %	0.015	1.03, large
	$V_{LVP\,3T}$ (m·s^{-1})	1.07 ± 0.15 (0.99 to 1.16)	0.85 ± 0.13 (0.77 to 0.93)	0.2 (0.1 to 0.3); 26.7 %	< 0.001	1.58, large
	SR_{1T} (Cyc·min^{-1})	57.48 ± 4.30 (55.10 to 59.86)	53.98 ± 3.91 (51.49 to 56.46)	3.5 (0.2 to 6.8); 6.5 %	0.038	0.85, large
	SR_{2T} (Cyc·min^{-1})	56.45 ± 4.63 (53.89 to 59.02)	53.93 ± 3.45 (51.73 to 56.12)	2.5 (-0.8 to 5.8); 4.7 %	0.128	0.61, medium
	SR_{3T} (Cyc·min^{-1})	55.94 ± 5.37 (52.97 to 58.91)	52.47 ± 2.96 (50.59 to 54.35)	3.5 (-0.1 to 7); 6.6 %	0.056	0.78, medium
	SL_{1T} (m)	1.75 ± 0.16 (1.67 to 1.84)	1.63 ± 0.19 (1.52 to 1.75)	0.1 (0 to 0.3); 7.3 %	0.081	0.70, medium
	SL_{2T} (m)	1.41 ± 0.15 (1.33 to 1.50)	1.38 ± 0.16 (1.28 to 1.48)	0.0 (-0.1 to 0.2); 2.3 %	0.602	0.20, small
	SL_{3T} (m)	1.18 ± 0.16 (1.10 to 1.27)	1.01 ± 0.16 (0.91 to 1.11)	0.2 (0.1 to 0.3); 17.7 %	0.008	1.11, large
	SI_{1T} (m·s^{-1})	2.95 ± 0.44 (2.70 to 3.19)	2.41 ± 0.44 (2.13 to 2.69)	0.5 (0.2 to 0.9); 22.5 %	0.004	1.23, large
	SI_{2T} (m·s^{-1})	1.88 ± 0.35 (1.69 to 2.08)	1.72 ± 0.31 (1.52 to 1.91)	0.2 (-0.1 to 0.4); 9.8 %	0.202	0.51, medium
	SI_{3T} (m·s^{-1})	1.32 ± 0.29 (1.16 to 1.48)	0.90 ± 0.25 (0.74 to 1.06)	0.4 (0.2 to 0.6); 46.8 %	< 0.001	1.54, large
	$[La^-]_{basal}$ (mmol·L^{-1})	2.3 ± 0.7 (1.9 to 2.6)	2.3 ± 0.6 (1.9 to 2.7)	0.0 (-0.6 to 0.5); -2.1 %	0.852	0.07, small
	$[La^-]_{1T}$ (mmol·L^{-1})	2.3 ± 0.8 (1.8 to 2.7)	2.4 ± 0.4 (2.2 to 2.6)	-0.1 (-0.6 to 0.4); -4.7 %	0.655	0.18, small
	$[La^-]_{2T}$ (mmol·L^{-1})	4.1 ± 0.9 (3.6 to 4.6)	4.3 ± 0.9 (3.7 to 4.9)	-0.2 (-0.9 to 0.6); -3.8 %	0.651	0.18, small
	$[La^-]_{3T}$ (mmol·L^{-1})	5.7 ± 1.5 (4.9 to 6.5)	5.6 ± 2.1 (4.2 to 6.9)	0.2 (-1.3 to 1.6); 2.9 %	0.815	0.09, small
	$[La^-]_{peak}$ (mmol·L^{-1})	10.7 ± 4.1 (8.4 to 13.0)	10.4 ± 3.2 (8.4 to 12.5)	0.3 (-2.7 to 3.3); 2.8 %	0.841	0.08, small
	$[La^-]_{net}$ (mmol·L^{-1})	8.5 ± 4.1 (6.2 to 10.8)	8.1 ± 2.8 (6.3 to 9.9)	0.3 (-2.5 to 3.2); 4.2 %	0.808	0.10, small
Pull-up	PUv_{avg} (m·s^{-1})	0.89 ± 0.19 (0.79 to 1.99)	0.49 ± 0.19 (0.37 to 0.61)	0.4 (0.3 to 0.6); 83 %	< 0.001	2.11, large
	PUf_{avg} (N)$^{a\$}$	725.02 ± 74.75 (683.63 to 766.42)	610.63 ± 132.10 (526.70 to 694.56)	114.4 (31.5 to 197.3); 18.7 %	0.009	1.10, large
	PUp_{vg} (W)$^{a\$}$	634.18 ± 150.61 (550.77 to 717.58)	304.68 ± 195.58 (180.42 to 428.95)	329.5 (192.4 to 466.6); 108.1 %	< 0.001	1.92, large
50m all-out	T50 (s)	27.13 ± 1.33 (26.39 to 27.87)	30.82 ± 1.23 (30.04 to 31.6)	-3.7 (-4.7 to -2.7); -12 %	< 0.001	2.86, large
	T25 (s)	13.34 ± 0.67 (12.97 to 13.71)	15.07 ± 0.56 (14.71 to 15.42)	-1.7 (-2.2 to -1.2); -11.5 %	< 0.001	2.77, large
	T25-50 (s)	13.79 ± 0.68 (13.42 to 14.17)	15.75 ± 0.70 (15.31 to 16.19)	-1.9 (-2.5 to -1.4); -12.4 %	< 0.001	2.84, large
	Clean swimming speed (m·s^{-1})	1.70 ± 0.09 (1.65 to 1.75)	1.51 ± 0.06 (1.47 to 1.55)	0.2 (0.1 to 0.3); 12.6 %	< 0.001	2.47, large
	SR_{50} (Cyc·min^{-1})	52.00 ± 2.56 (50.59 to 53.42)	51.07 ± 3.27 (48.99 to 53.15)	0.9 (-1.4 to 3.2); 1.8 %	0.415	0.32, small
	SL_{50} (m)	1.96 ± 0.13 (1.89 to 2.04)	1.78 ± 0.16 (1.68 to 1.88)	0.2 (0.1 to 0.3); 10.1 %	0.003	1.27, large
	SI_{50} (m^2·s^{-1})	3.34 ± 0.37 (3.13 to 3.54)	2.69 ± 0.33 (2.48 to 2.9)	0.6 (0.4 to 0.9); 24.2 %	< 0.001	1.85, large

V_0: maximum velocity at zero load; L_0: maximum load at zero velocity; Slope: steepness of the linear regression line for the load-velocity relationship; V_{LVP}: swim velocity during load velocity profile trials; SR, SL, SI: stroke rate, length and index, respectively; 1T, 2T, 3T: first, second, and third trial, respectively; $[La^-]$: blood lactate concentration; basal: basal blood lactate concentration; peak: peak blood lactate concentration; net: blood lactate concentration difference between the $[La^-]$ peak and basal values; PUv_{avg}: average propulsive velocity; PUf_{avg}: average propulsive force; PUp_{avg}: average propulsive power; T: time taken to complete the given distance; SR_{50}, SL_{50} and SI_{50}: average values of the 50m all-out trial.