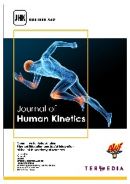

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Section III – Sports and Physical Activity

Evaluation of Land-Based Simulated Data and In-Water Assessments for Butterfly and Freestyle Swimming Strokes

by

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This study investigated the relationship between isometric pull forces measured during land-based simulations and propulsive forces generated in water during arm pulls and leg kicks in butterfly and freestyle swimming techniques. Thirty male competitive swimmers (age: 19.47 ± 2.35 years; FINA points: 626.57 ± 65.21; body height: 184.10 ± 5.14 cm; body mass: 70.61 ± 8.91 kg; training experience: 9.53 ± 2.00 years; BMI: 22.17 ± 2.03 kg/m^2) volunteered to participate in the study. Isometric arm pull forces were measured on a swim bench (Vasa Swim Trainer), while aquatic forces were assessed using a custom-built tethered system to isolate kick, pull and full-stroke conditions. The results indicated that arm contribution to propulsion was 66.91% in butterfly and 69.03% in freestyle, while legs contributed 33.09% and 30.97%, respectively. Significant positive correlations ($p < 0.05$) were found between land-based and water-based force data and swimming performance. These findings suggest that such simulations can be useful for both short-term performance assessment and long-term training strategy development.

Keywords: *tethered swim; dryland training; swim performance; kick force; pull force*

Introduction

To enhance swimming performance, both arm and leg propulsive forces in water play critical roles. Consequently, swimmers often engage in both land-based and aquatic training models designed to improve these specific force output. The ability to produce such force is not only a function of muscular strength, but also the swimmer's efficiency in applying that force effectively in water (Dominguez-Castells and Arellano, 2011). Swimmers generate forward motion by counteracting water resistance through hydrodynamic reaction forces (Vorontsov and Rumyantsev, 2000; Psycharakis et al., 2011). The magnitude of generated propulsion is influenced by several factors including the evaluation method, the stroke type, and gender (Ozuak, 2025; Santos et al., 2023).

The primary goal of coaches and sports scientists is to enhance swimmers' pull and kick force production during training, both in and out of the water, to improve swimming speed. For this reason, athletes' development is tracked through structured short-, medium-, and long-term training interventions. Determination of the effects of land-based applications on water performance and evaluating how land-based force assessments reflect in-water performance requires a comparative analysis of both testing environments.

Various land-based tools such as resistance bands, swim benches, and ergometers have been developed to simulate swim-specific force training (Loturco et al., 2016; Morouço et al., 2011). However, kinetic and kinematic assessments in the water are often more complex due to the challenges of direct measurement (Kwok et al., 2021). Therefore, the reflection of land based strength assessments on in-water performance is a commonly used proxy.

Most studies examining upper and lower limb strength in swimmers focus on the freestyle

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stroke (Amaro et al., 2017; Kwok et al., 2021). In several of these, swimmers' propulsive forces have been evaluated using tethered systems with force sensors (Haskins et al., 2023). Land- and water-based assessments have also employed tools such as load cells, force plates, and swim benches (Morais et al., 2020; Ruiz-Navarro et al., 2020).

Gourgoulis et al. (2014) suggested that kicking contributed not only to direct propulsion, but also to maintaining the body position in the water, reducing hydrodynamic drag. Although leg kick contribution to forward motion varies with the style and technique, estimates in freestyle suggest a contribution ranging between 10 and 40% (Mezêncio et al., 2020; Morris et al., 2019).

Given the mechanical similarities between butterfly and freestyle strokes in terms of upper limb movement, there is a need for comparative studies examining the relationship between land-based pull force simulation and water-based arm and leg force production across both techniques.

Methods

Participants

Thirty male competitive swimmers (age: 19.47 ± 2.35 years; FINA score: 626.57 ± 65.21; body height: 184.10 ± 5.14 cm; body mass: 70.61 ± 8.91 kg; training experience: 9.53 ± 2.00 years; BMI: 22.17 ± 2.03 kg/m^2) voluntarily participated in the study. Ethical approval was granted by the Marmara University Faculty of Medicine Clinical Research Ethics Committee. İstanbul, Türkiye (protocol code: 09.2024.430: approval date: 22 April 2024), and the study was conducted in accordance with the ethical standards of the Declaration of Helsinki. The volunteer participants whose data were shared in the article were informed abouth the study's aim, procedures, potential risk as well as benefits, and their consent was obtained by signing a consent form. A priori power analysis was conducted using G*Power 3.1 software for the repeated measures design (one-way), assuming $\alpha = 0.05$, effect size (d) = 1.45, and power ($1 - \beta$) = 1.0. The analysis was based on the total pull force measurements for butterfly and freestyle techniques.

Data Collection Instruments

The tests were conducted in two stages: on land and in water. In both settings, force measurements were recorded using a custom load cell system connected to a digital indicator and software (Daysensor, China, Model DYLY-107; Tuncel, 2024). Land-based tests were performed on a Vasa Swim Trainer (Vasa Inc., Essex Junction, VT, USA) (Figure 1). In the land-based assessments, swimmers' maximum arm strength was measured in three (catch, pull, push) different phases (Figure 1). In the water-based assessments, swimmers' maximum strength was evaluated under three testing conditions for both freestyle and butterfly techniques (a full-stroke test, a pull test, and a kick test) (Figure 2). Participants' body height was measured using a stadiometer, body mass and the BMI were recorded using a Tanita SC-330 analyzer. All testing sessions, both land and aquatic, were video-recorded using a GoPro Hero5 (San Mateo, CA) for analysis verification.

Water-based data were collected at the Marmara University Sports Sciences Faculty swimming pool, and land-based data were collected at the Marmara University Sports Sciences Athlete Health Application and Research Center laboratory.

Land-Based Testing Procedures

In the land-based assessments, the Vasa Swim Trainer's handle cords were adjusted based on each swimmer's arm length. A load cell mounted on a pivoting mechanism allowing perpendicular motion relative to the direction of the pulling force was used for measurements (Figure 1). Maximum isometric forces during the catch, pull, and push phases of the stroke were recorded (Figure 1) following the definitions by Callaway (2015) and Cortesi et al. (2021).

For each phase, swimmers applied force using their right arm, left arm, and both arms simultaneously. Each movement was repeated three times, with each repetition lasting 10 s. One-minute rest intervals were provided between repetitions, and a three-minute rest was given between transitions from catch to pull and from pull to push phases.

Catch Phase

The catch phase was defined as the motion from the hand entry to the initiation of the pull, approximately corresponding to a 30° arm position relative to the water surface (Riewald and Rodeo, 2015) (Figure 1a). Maximum and average forces applied via the right, the left, and both arms were recorded during this phase.

Pull Phase

This phase was defined as the downward motion of the hand to a vertical position aligned with the shoulder (90°) (Figure 1b). Maximum and average isometric pull forces were measured while swimmers performed this movement on the swim bench.

Push Phase

The push phase was defined as the motion from the end of the pull to the point where the hand passed below the swimsuit line (Figure 1c). Maximum and average forces were recorded using the same measurement approach during this final extension movement.

Water-Based Testing Procedures

A custom-designed tethered setup was used in the aquatic force assessments. It consisted of a 5-m steel cable with one end attached to a waist harness worn by the swimmer and the other to a starting block-mounted load cell (Morouço et al., 2011). Three testing conditions were implemented in both freestyle and butterfly techniques:

Full-Stroke Swimming Test: Swimmers were instructed to swim until the tether cable was taut, then exert maximal effort for 10 s using both arms and legs (Figure 2a). Total propulsive force was recorded.

Pull Test: Two pull buoys were used to restrict leg motion—one placed between the knees and the other between the heels and knees (Figure 2b). Swimmers performed 10 s of maximal arm-only swimming after the tether became taut.

Kick Test: With a kickboard held by the hands to restrict arm movement, swimmers performed maximal effort kicking for 10 s once the tether was taut (Figure 2c).

Each test was performed separately for freestyle and butterfly techniques. Three-minute rest intervals were given between repetitions, and a 10-min rest interval between different stroke conditions (Carvalho et al., 2019).

25-m Swimming Performance Test

In a 25-m pool, each participant performed maximal-effort 25-m trials for each condition (full stroke, arms only, and legs only) in both freestyle and butterfly strokes. Times were recorded independently by three national-level coaches. Three-minute rest intervals were given between repetitions, and 10-min intervals between stroke types. All swimmers received detailed information and unlimited practice opportunities before testing.

Warm-Up Protocol

Tests were conducted over two separate days, one week apart. Land based tests were performed on day one, and in-water tests on day two. For land-based testing, participants completed a 20-min dynamic warm-up, including knee raises, lunges, arm rotations, and general stretching. The water-based warm-up included: 300-m choice swim, 6 × 50-m (kick, pull, drill), 6 × 25-m (easy to fast), and 50-m easy swim.

Data Analysis

Maximum and average force values were extracted from the highest among three repetitions for each condition. Average isometric force values were calculated by taking the mean of the 8-s period excluding the first and last seconds of each 10-s trial.

Contribution Calculations

The contributions of the kick and arm actions to swimming performance were calculated using the following formulas:

Kick Contribution (%). The relative contribution of the kick to propulsion was calculated as:

Kick Contribution (%) = (Kick Force / (Kick Force + Pull Force)) × 100

*Pull Contribution (%)***.** The relative contribution of the pull during swimming was calculated as:

Pull Contribution (%) = (Pull In-Water Force / (Kick + Pull Force)) × 100

Difference between Full Stroke and Total (Kick + Pull) (%):

To assess the efficiency or synergy of full stroke motion versus the sum of isolated components (kick + pull), the percentage difference was calculated as:

$$\% \text{ Difference} = \text{Total} \times 100 / (\text{Full Stroke} + \text{Total}) - \text{Full Stroke} \times 100 / (\text{Full Stroke} + \text{Total})$$

Normal distribution was checked using the Shapiro-Wilk test. Differences between the right and the left arm output were analyzed with paired *t*-tests (or Wilcoxon where appropriate). ANOVA and Kruskal-Wallis tests were used for between-group comparisons. Bonferroni-corrected Mann-Whitney U tests were applied when significant differences were found. Correlations were analyzed using Pearson or Spearman correlation tests as appropriate. All analyses were conducted using Jamovi®, open-source software (version 2.6.44, Sydney, Australia), and the level of significance was set at $p < 0.05$. Descriptive statistics were reported as mean ± standard deviation (SD), and median values where relevant.

Results

The findings obtained from the study are presented in Tables 1–4.

While statistically significant differences were found between the right and left arms only during the pull and push phases of the butterfly stroke simulation on the Vasa swim trainer, differences were observed in all phases between the right and left arms during the freestyle stroke simulation.

In butterfly, pull contribution was calculated as 66.91% and leg contribution as 33.09%, while in freestyle, these were 69.03% and 30.97%, respectively. Significant differences were observed between the full stroke and total force values (kick + pull) for both styles.

Relationships were identified among the catch, pull, and push phases, as well as the total duration of these phases during land-based butterfly stroke simulations performed on the Vasa Swim Trainer, and the pull and leg velocities during 25-m butterfly swimming in the pool, along with water-based load cell test results including total kick+pull, only kick (maximum), and 10-s average load values. A significant relationship was found between the 10-s average load cell values for only arm movement in water and the maximum and average forces of the pull phase, as well as the catch, pull, and push phase values recorded on the Vasa Swim Trainer. However, no significant relationship was observed between the full-stroke loadcell values and the land-based simulation data.

Strong relationships were identified among the catch, pull, and push phases, as well as the total duration of these phases during the freestyle stroke simulation on the Vasa Swim Trainer, and the arm and leg velocities during a 25-m freestyle swim in the pool, along with the maximum and 10-s average loadcell values obtained from only-kick tests in water. Furthermore, numerous and strong correlations were found between the 10-s maximum loadcell values for total kick+pull efforts in water and the pull phase variables. Similarly, significant relationships were observed between the 10-s average load cell values for the kick and total kick+pull conditions and the pull phase data. However, fewer and weaker correlations were identified between the 10-s average loadcell values for arm movements and the maximum and average pull phase forces recorded on the Vasa Swim Trainer.

Discussion

This study investigated the effects of force output during three phases (catch, pull, push) of simulated butterfly and freestyle arm strokes on a Vasa Swim Trainer on land, in comparison with in-water measurements of arm pulls, leg kicks, and full stroke swim force output. Additionally, the influence of these variables on swimming performance was examined.

During the freestyle simulation tests conducted on land, force discrepancies were identified between the right and left arms across the catch, pull, and push phases. These asymmetries are believed to stem from the swimmers habitual unilateral breathing patterns (typically to the right), as supported by findings from Seifert et al. (2005) as well as Fone and van den Tillaar (2022). Similarly, significant differences were observed between the right and left arm forces in the butterfly stroke. Since butterfly involves synchronous and symmetrical arm movements, the forces produced are expected to reflect this symmetry. Morais et al. (2020) also emphasized that symmetrical arm movements are essential in the butterfly stroke. Prior studies have noted that improvements in upper-body strength performance are generally transferable across different swimming styles (Fone and van den Tillaar, 2022; Morouço et al., 2012). The predominance of freestyle-based training in the pool appears to have contributed to improvements in arm-pull force in both swimming strokes. The statistically significant difference observed in the performance of the left arm in both butterfly and freestyle swimming tests may be attributed to the participants' primary stroke being freestyle and their habitual breathing pattern to the right side. The asymmetries identified in our study highlight the potential value of such data in forming a robust basis for the design of targeted interventions in muscular strength, flexibility, and technical execution, with the ultimate goal of improving athletic performance (Knihs et al., 2025; Sanders et al., 2015).

Table 1. Right and left arm force values (catch, pull, push phases, and total) during simulated freestyle and butterfly arm strokes performed on the Vasa Swim Trainer.

	Butterfly (n = 30)				Freestyle (n = 30)			
	Right Arm Mean ± Sd	Left Arm Mean ± Sd	Right + Left Mean ± Sd	*p*	Right Arm Mean ± Sd	Left Arm Mean ± Sd	Right + Left Mean ± Sd	*p*
Catch Phase Maks (kg)	19.11 ± 5.01	20.03 ± 4.96	39.13 ± 9.80	0.063	19.82 ± 5.73	21.48 ± 5.75	41.30 ± 11.14	0.003*
Catch Phase Ave (kg)	16.62 ± 4.50	17.25 ± 4.66	33.88 ± 8.15	0.116	17.22 ± 5.31	18.28 ± 5.18	35.50 ± 10.27	0.016*
Pull Phase Maks (kg)	19.27 ± 3.91	20.70 ± 4.20	39.96 ± 7.79	0.003*	20.58 ± 4.59	21.97 ± 4.54	42.56 ± 8.72	0.012*
Pull Phase Ave (kg)	16.56 ± 3.48	17.69 ± 4.19	34.25 ± 7.40	0.006*	17.91 ± 4.30	18.74 ± 4.09	36.66 ± 8.04	0.043*
Push Phase Maks (kg)	24.44 ± 6.28	25.52 ± 6.94	49.96 ± 12.78	0.098	24.24 ± 6.01	26.39 ± 6.69	50.63 ± 12.01	0.013*
Push Phase Ave (kg)	19.91 ± 6.27	21.17 ± 7.09	41.09 ± 12.99	0.022*	21.25 ± 5.31	22.20 ± 5.58	43.46 ± 10.52	0.047*
Cath, Pull, Push Phase Maks (kg)	60.79 ± 17.81	64.10 ± 19.23	129.05 ± 28.69	0.015*	62.55 ± 18.73	67.59 ± 19.85	134.48 ± 29.82	0.001*
Cath, Pull, Push Phase Ave (kg)	51.38 ± 15.70	54.31 ± 17.90	109.21 ± 27.24	0.019*	54.57 ± 16.75	57.31 ± 17.33	115.61 ± 26.98	0.012*

* $p < 0.005$

Table 2. Water-based force data for the butterfly and freestyle kick, pull, total (kick + pull), and full stroke along with contribution percentages and differences between full stroke and total values.

	Butterfly (n = 30)		Freestyle (n = 30)	
	Maximum Mean ± Sd	Avarage Mean ± Sd	Maximum Mean ± Sd	Avarage Mean ± Sd
Kick (kg)	14.80 ± 4.00	8.41 ± 2.41	9.53 ± 1.89	5.85 ± 1.56
Pull (kg)	30.83 ± 9.45	8.72 ± 2.57	21.71 ± 6.11	12.58 ± 3.23
Full Stroke (kg)	39.74 ± 9.40	13.61 ± 3.52	28.15 ± 5.26	16.10 ± 3.42
Total (kick + pull) (kg)	45.63 ± 11.72	17.13 ± 4.74	31.24 ± 7.37	18.43 ± 4.23
Contribution of the kick (%)	33.09	49.25	30.97	32.00
Contribution of the pull (%)	66.91	50.75	69.03	68.00
Full − total diff (kg)	−5.89 ± 6.50	−3.52 ± 2.08	−3.09 ± 5.99	−2.33 ± 2.00
Full − total diff (%)	11.30	19.74	11.71	11.99
25-m kick speed (m/s)	1.56 ± 0.16		1.56	
25-m pull speed (m/s)	1.83 ± 0.16		1.94 ± 0.11	
25-m full stroke speed (m/s)	1.97 ± 0.14		2.08 ± 0.11	

Table 3. Correlation of land-based (left and right total forces) and water-based tests in the butterfly stroke.

		Land-based							
		Catch Phase Max (kg)	Catch Phase Ave (kg)	Pull Phase Max (kg)	Pull Phase Ave (kg)	Push Phase Max (kg)	Push Phase Ave (kg)	Cath, Pull, Push Phase Max (kg)	Cath, Pull, Push Phase Ave (kg)
Water-based	25-m Full Stroke	0.612**	0.576**	0.573**	0.616**	0.619**	0.493**	0.647**	0.654**
	Speed (m/s)	0.000	0.001	0.001	0.000	0.000	0.006	0.000	0.000
	25-m Pull Speed (m/s)	0.512**	0.456*	0.464**	0.482**	0.416*	0.336	0.503**	0.481**
		0.004	0.011	0.010	0.007	0.022	0.070	0.005	0.007
	25-m Kick Speed (m/s)	0.533**	0.527**	0.538**	0.573**	0.565**	0.405*	0.589**	0.600**
		0.002	0.003	0.002	0.001	0.001	0.026	0.001	0.000
	Kick Max (kg)	0.488**	0.422*	0.578**	0.618**	0.545**	0.516**	0.577**	0.568**
		0.006	0.020	0.001	0.000	0.002	0.004	0.001	0.001
	Kick Ave (kg)	0.513**	0.417*	0.532**	0.539**	0.530**	0.457*	0.561**	0.537**
		0.004	0.022	0.002	0.002	0.003	0.011	0.001	0.002
	Pull Max (kg)	0.346	0.284	0.371*	0.317	0.216	0.284	0.347	0.283
		0.061	0.128	0.044	0.088	0.253	0.129	0.061	0.130
	Pull Ave (kg)	0.382*	0.293	0.395*	0.372*	0.319	0.329	0.399*	0.350
		0.037	0.116	0.031	0.043	0.086	0.076	0.029	0.058
	Total Kick + Pull Max	0.445*	0.373*	0.496**	0.466**	0.360	0.404*	0.476**	0.422*
	(kg)	0.014	0.042	0.005	0.009	0.051	0.027	0.008	0.020
	Total Kick + Pull Ave	0.468**	0.371*	0.485**	0.476**	0.443*	0.411*	0.502**	0.463**
	(kg)	0.009	0.044	0.007	0.008	0.014	0.024	0.005	0.010
	Full Stroke Max (kg)	0.232	0.137	0.224	0.211	0.174	0.258	0.232	0.185
		0.216	0.472	0.235	0.263	0.358	0.169	0.218	0.327
	Full Stroke Ave (kg)	0.300	0.208	0.344	0.329	0.298	0.338	0.341	0.300
		0.107	0.270	0.063	0.076	0.110	0.068	0.065	0.107

* $p < 0.05$; ** $p < 0.01$

Table 4. Correlation of land-based (left and right total forces) and water-based tests in the freestyle stroke.

		Land-based							
		Catch Phase Max (kg)	Catch Phase Ave (kg)	Pull Phase Max (kg)	Pull Phase Ave (kg)	Push Phase Max (kg)	Push Phase Ave (kg)	Cath, Pull, Push Phase Max (kg)	Cath, Pull, Push Phase Ave (kg)
Water-based	25-m Full Stroke Speed	0.645**	0.638**	0.722**	0.736**	0.681**	0.654**	0.726**	0.717**
	(m/s)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	25-m Pull Speed (m/s)	0.602**	0.608**	0.656**	0.687**	0.578**	0.556**	0.649**	0.653**
		0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
	25-m Kick Speed (m/s)	0.535**	0.508**	0.519**	0.535**	0.442*	0.479**	0.529**	0.539**
		0.002	0.004	0.003	0.002	0.014	0.007	0.003	0.002
	Kick Max (kg)	0.366*	0.336	0.551**	0.601**	0.531**	0.475**	0.512**	0.492**
		0.047	0.070	0.002	0.000	0.003	0.008	0.004	0.006
	Kick Ave (kg)	0.605**	0.564**	0.665**	0.671**	0.549**	0.610**	0.642**	0.653**
		0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.000
	Pull Max (kg)	0.089	0.082	0.305	0.356	0.166	0.118	0.189	0.183
		0.642	0.665	0.102	0.053	0.381	0.535	0.318	0.332
	Pull Ave (kg)	0.156	0.139	0.450*	0.517**	0.274	0.231	0.300	0.297
		0.410	0.462	0.012	0.003	0.143	0.219	0.107	0.111
	Total Kick + Pull Max	0.167	0.154	0.393*	0.449*	0.273	0.219	0.287	0.278
	(kg)	0.378	0.416	0.031	0.013	0.144	0.245	0.124	0.137
	Total Kick + Pull Ave	0.342	0.314	0.589**	0.642**	0.412*	0.401*	0.466**	0.467**
	(kg)	0.064	0.091	0.001	0.000	0.024	0.028	0.009	0.009
	Full Stroke Max (kg)	0.268	0.231	0.506**	0.536**	0.422*	0.346	0.418*	0.383*
		0.153	0.220	0.004	0.002	0.020	0.061	0.022	0.037
	Full Stroke Ave (kg)	0.300	0.262	0.568**	0.615**	0.409*	0.336	0.443*	0.414*
		0.107	0.162	0.001	0.000	0.025	0.070	0.014	0.023

* $p < 0.05$; ** $p < 0.01$

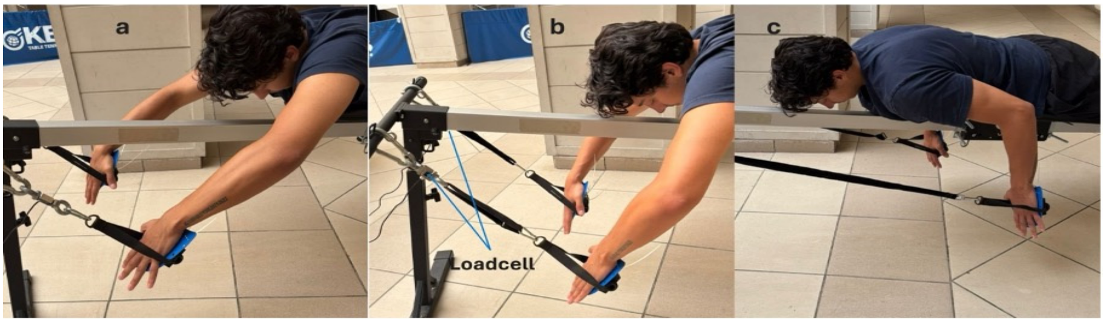

Figure 1. Experimental setup for land-based testing using a Vasa Swim Trainer to simulate the three distinct phases: (a) a catch, (b) a pull, and (c) a push.

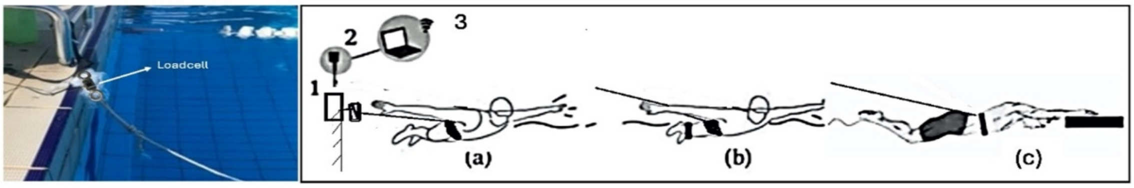

Figure 2. The experimental setup for water-based testing consisted of three main components: (1) a load cell, (2) an indicator, and (3) a software interface. Three types of tests were conducted: (a) a full-stroke test, (b) a pull test, and (c) a kick test.

Deschodt et al. (1999) reported that leg kicks contributed to swim speed in two ways: by helping the swimmer maintain a streamlined, horizontal body position and by directly enhancing propulsion. Amara et al. (2022) highlighted the importance of assessing arm and leg propulsion forces in water as a valuable indicator for swimmers' development. Regular monitoring of arm pull and leg kick forces can directly impact the effectiveness of training planning. Morris et al. (2016) found that leg kicks could contribute approximately 11% to swimming velocity. In the current study, the data obtained from leg kick tests aid in determining the extent to which these forces influence performance in both freestyle and butterfly strokes.

According to maximum force output obtained via a load cell system in water during freestyle swimming, legs contributed 31% and arms 69% to the total (kick + arm) force production (Table 2). These findings are consistent with previous studies by Swain (2000), Wei et al. (2014), Morouço et al. (2015) and Morris et al. (2019), who used a similar experimental setup, as well as with the contributions of upper and lower extremities to swimming performance described in the studies.

The butterfly stroke involves simultaneous arm pulls and two dolphin kicks (Chollet et al., 2006; Strzała et al., 2017). In the current study, force tests were conducted under three conditions in water: only-arm strokes, only dolphin kicks, and full butterfly strokes. During the dolphin-only tests, kick frequency was higher than during full-stroke conditions, as arm movements were absent. Since the dolphin kick is performed independently of the arm movement, the average force generated by the leg kicks has been observed to exceed the force produced during normal butterfly swimming (Swain, 2000) (Table 2). Based on load cell measurements, dolphin kicks contributed 33% and arm pulls 67% to total force output in the butterfly stroke (Table 2). To our knowledge, there is no existing literature providing similar butterfly-specific force contribution data, indicating that this study fills a gap in the field.

Sex-related differences have been shown to influence the relationship between the rate of force development and short-distance front crawl swimming speed, indicating that propulsive force characteristics cannot be interpreted independently of sex (Chen et al., 2025). Accordingly, coaches and practitioners are encouraged to explicitly consider sex-specific adaptations when designing training programs aimed at improving swimming propulsion. From a technical perspective, performance assessments in swimming frequently emphasize the relative contributions of arm and leg actions, with technical efficiency presumed to increase as the discrepancy between force output obtained from isolated limb actions and this produced during full-stroke swimming decreases (Morris et al., 2019; Santos et al., 2024). In the present study, the small differences observed between isolated and full-stroke force output in both swimming strokes suggest that the participating swimmers demonstrated a high level of technical proficiency (Table 2). Such findings support previous evidence indicating that isolated force assessments may provide valuable insight into swimmers' capacity to generate effective in-water propulsion and to efficiently transfer this force into forward swimming velocity, particularly in developing swimmers (Oliveira et al., 2020).

Amaro et al. (2014) and Oz et al. (2024) indicated that land-based swim-specific exercises not only improved swimming technique, but also developped force generation patterns consistent with in-water stroke mechanics. Regarding the transfer of strength gains to swimming, Vorontsov (2011) stated that transferring land-based performance gains into swimming performance required an adaptation period. Therefore, these gains should be appropriately timed and integrated into training programs. Effective training and testing protocols should incorporate both land-based and in-water components to support short-term performance evaluation and long-term development of arm and leg function. This dual approach aids in addressing performance deficits and designing strategic training plans (Santos, 2024; Soncin et al., 2017). Land based resistance training has been shown to improve strength and should thus be included alongside in-water training to enhance overall swimming performance (Morais et al., 2020; Wirth et al., 2022). The positive transfer of land-based acquired capacities (e.g., proper stroke mechanics) can be a meaningful contributor to in-water performance, as it helps assess the relationship between applied force and swimming velocity (Amaro et al., 2014; Chalkiadakis et al., 2023; Ruiz-Navarro et al., 2024).

In this study, positive correlations were observed between the force values obtained in land-based and in-water tests for both freestyle and butterfly strokes. Swimmers who produced high arm pull forces on land also demonstrated strong force production in water (Tables 3 and 4). These findings are consistent with previous literature.

Conclusions

This study identified a strong relationship between force data obtained from land-based arm pull simulations and in-water performance measures, including swimming speed. The results from load cell-based swimming tests in water appear to be a reliable protocol for evaluating swimmers' force production and may serve as a useful predictor of short-distance swimming performance. In this context, land based swimming simulations are believed to contribute positively to in-water performance.

Given that swimmers who exhibit high arm force on land are able to achieve greater propulsion and speed in water, it is recommended that training protocols emphasize the catch, pull, and push phases of freestyle and butterfly strokes performed on swim benches. These types of tests may also be beneficial for monitoring the aquatic force development of developing swimmers.

Through analysis of the force output obtained from in-water simulations including only kick, only pull, total, and full swim trials using load cells and their contribution to swimming performance, it is possible to make informed evaluations of each swimmer. Based on these assessments, training plans can be adjusted to address specific weaknesses.

Monitoring force asymmetries between swimmer's dominant and non-dominant arms via land-based tests may help guide technical interventions. Encouraging bilateral breathing, for instance, can promote the development of symmetrical force production and improve stroke mechanics.

Ultimately, these testing protocols can be instrumental for both short-term evaluation of arm and leg performance and the long-term development of targeted training strategies to address performance deficits.

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