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The Effect of Concurrent Resistance Training on Tethered Force, Lower Limbs Strength, Anaerobic Critical Velocity and Swimming Performance: A Randomized Controlled Trial

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Abstract: Combining pool based + resistance workouts both in the pool and on dry land is a valuable approach to enhance breaststroke swimming performance. However, few investigations have been conducted on this topic. Through a randomized controlled trial study, we investigated the effects of 10-week concurrent resistance training program, which integrates resistance workouts both in the pool and on dry land, on tethered force, lower limb strength, anaerobic critical velocity, and swimming performance in regional age-group breaststroke swimmers. Methods: Regional age-group swimmers (N = 24, males) were randomly divided into two groups. The experimental group (EG: 15.1 ± 0.5 years old) performed combined pool based + resistance workouts both in the pool and on dry land. The control group (CG: 15.1 ± 0.7 years old) performed their usual training, i.e. pool based + resistance workouts on dry land only. Tethered swimming force, muscular strength, anaerobic critical velocity, and swimming performance and technique were evaluated before and after 10 weeks. Results: Improvements were observed in EG vs. CG in mean force (30.04%, $p = 0.02$; $d = 0.75$), one-repetition maximum back squat (20.57%, $p = 0.01$; $d = 2.05$), maximal force (19.23%, $p = 0.03$; $d = 0.69$), and anaerobic critical velocity (4.2%, $p = 0.04$; $d = 0.61$). The 50 and 200-m breaststroke performance times improved (4.3 and5.4%, p=0.01, d=0.88-0.92, respectively) for 10 weeks. Conclusion: With the increasing demands of contemporary swimming competitions, which often include heats, semifinals, and finals, achieving optimal physical fitness to compete at an elite level in every round is vital for swimmers. The combination of resistance training workouts both in the pool and on dry land seems to enhance swimming performance in age-group swimmers, particularly at sprint to middle distance breaststroke swimmers.

Keywords: exercise physiology; physical fitness; training process; sports training; swimming; training load; training and testing; breaststroke

1. Introduction

Research investigating the impact of dry-land strength and conditioning on swimming performance has been influenced by the specificity of training methods [1] and training intensity [2,3]. The training approaches encompassed three primary perspectives: dry-land strength training, specific in-water resistance training, and concurrent training [4]. Dry-land strength training refers to a conventional resistance training approach that employs a gym-based strength program and swim-like resistance exercises utilizing a swim bench [5] to primarily enhance a swimmer's strength and power [6,7]. Substantial in-water submaximal strength training is performed through focused in-water resistance training, incorporating leg kicking exercises [8], resistance bands, hand paddles, or

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parachutes to counteract increased resistance [9–12]. Concurrent training in competitive swimmers, combining a strength training program together with swimming training [4], shows to enhance physiological changes both in aerobic and anaerobic capacities, energy expenditure during locomotion, and maximal power [13].

The dynamic process of training periodization is one of the most essential areas of training theory in sports. At the top of the hierarchical periodized system is multiyear preparation, followed by macrocycles, which are typically divided into three training periods over a season or year. The initial preparatory period involves high-volume training at low to moderate intensities, with varied exercises to build general physical and technical skills. The second period emphasizes more sport-specific work, while the third, the competition period, includes race-pace-specific exercises with a reduced training volume [3]. Besides, It is well reported that strength and conditioning programs designed for young swimmers should include a wide variety of strength training practices in their periodized strength training programme [4,14,15]. Traditionally, strength and conditioning programmes following to periodization emphasize the development of muscle endurance through the application of moderate external loads. This involves performing 2-3 sets of 6-8 repetitions, utilizing weights that constitute 50-75% of the individual's one-repetition maximum (1-RM) [9,16]. Conversely, substantial loads are employed to increase maximum strength. This includes executing 3-5 sets of 3-5 repetitions, with weights above 85% of the individual's 1-RM, with a rest interval of 2-3 minutes between sets [9,17]. Moreover, to enhance speed strength and power, training with low to medium loads, generally between 30-60% of the individual's 1-RM [18].

Research in Strength and conditioning training for young swimmers has primarily focused on front-crawl technique [9,11,17,19] and butterfly [15], with little emphasis on lower limb strength and power in breaststroke. Breaststroke is a technically tricky stroke distinguished by intermittent propulsive phases, significant intracyclic velocity fluctuations, and a low average velocity [20]. Despite the technical limitations placed on swimmers in breaststroke events, ranging from novices to elite competitors, there exists considerable scope for individual variation in timing, coordination, neuromuscular activity, and pacing profiles [21].

From a biomechanical and physiological perspective, the breaststroke technique differs in the extent to which the upper and lower limbs contribute to the propulsive forces. Increased power significantly enhances propulsive force, with the lower limbs playing a crucial role [20,22]. Consequently, coaches and trainers utilize strength and conditioning programs to enhance kinematics, temporal patterns, and improve neuromuscular performance. However, the benefits of combine strength training programs on breaststroke performance enhancement (from 50 to 200-m), and these findings remain unclear in the literature. Thus, this study aimed to evaluate the effects of 10-week concurrent resistance training program, incorporating resistance workouts both in the pool and on dry land, on tethered force, lower limb strength, anaerobic critical velocity (AnCV), and swimming performance in regional age-group breaststroke swimmers. It was hypothesized that such an approach of combined pool-based resistance workouts (using a parachute, fins, hand paddles, and specific kicking sets) with dry-land resistance workouts (which included back squats: BS, reverse lateral lunges: RLL, and dumbbell sumo Romanian deadlifts: SRDL) would improve tethered force swimming, lower limb strength, AnCV, and breaststroke swimming performance from 50 to 200-m events.

2. Materials and Methods

2.1. Experimental Design

In this randomized controlled study, twenty-four male swimmers specializing in breaststroke were randomly assigned to either an experimental group (EG) or a control group (CG). The experimental group participated in a training program of combined pool based + resistance workouts both in the pool (using a parachute, fins, hand paddles, and specific kicking sets) and on dry land (which included BS, RLL, and SRDL). The control group performed their usual training, i.e., pool based + resistance workouts on dry land only. We measured breaststroke tethered swimming force (i.e., maximal force, mean force, fatigue index), maximum muscle strength (1-RM back squat), AnCV, swimming performance and technique (velocity, stroke rate: SR, stroke length: SL, and stroke index: SI) in 50, 100, and 200-m breaststroke swimming. These measurements were taken before and after 10 weeks of both training conditions during the first macrocycle of a traditional three-peak preparation program. Importantly, swimmers were explicitly told not to engage in any additional physical training routine focused on velocity and power throughout the duration of the trial. Before the beginning of their practices, all participants were free from any injuries.

2.2. Participants

A sample size of 24 participants was considered sufficient (software G * Power, version 3.1.9.6) with an alpha of 0.05, power of 0.80, and effect size of 0.5. Twenty-four breaststroke swimmers, competing at national and regional levels within their age categories, voluntarily participated in this study. The participants were assigned at random to participate in either the control group (CG, N = 12; age: 15.1±0.7 years; height: 176.4±1.8 cm; body mass: 67.4±1.7 kg; 19.6±0.27% of fat mass; competitive swimming experience: 3.8±0.8 years; 560±52 200-m breaststroke Word Aquatic points); or the experimental group (EG, N = 12; age: 15.1±0.5 years; height: 176.8±2.0 cm; body mass: 65.8±1.4 kg; 19.3±0.4% of fat mass; competitive swimming experience: 4.0±0.7 years; 578±36 200-m breaststroke World Aquatic points). The inclusion criteria were as follows: (i) had a minimum of 3 years of training experience; (ii) participated in at least 90% of the training period; (iii) free from current injury in the 10-week training period; and (iv) not participate in any other training program during the current study. Exclusion criteria were as follows: (i) poor health status and physical condition with potential medical problems, and (ii) incomplete participation in the training and testing program. Parents were informed about the benefits, risks of taking part and the entire evaluative and experimental process in the current study prior to signing an informed consent form, which was approved by the ethics board of the local university code G-HS047/2567(C1) and performed according to the Helsinki Declaration.

2.3. Procedures

2.3.1. Aquatic Resistance and Dry-Land Resistance Training

Pool-based training and swimming performance tests took place in a 50-m indoor pool with 25-27 and 27.2-28.1°C water and air temperatures, respectively and 64-68% relative humidity during the data collection period. Dry-land training and strength tests were performed in a fitness training room. Aquatic resistance training which included specific kicking sets, parachute, fins, and hand paddles was composed of two sessions per week. The water parachute, fins and hand paddles set were used (2-3 sessions in a week) immediately after the warm-up (i.e., 500 to 800-m of aerobic training [i.e., 55% to 80% of maximum heart rate]) on Tuesdays and Thursdays. On general phase (i.e., weeks 1- 6), swimmers completed 3 sets × 6 repetitions × 15-m with 60 seconds and 5 minutes of rest between repetitions and sets, respectively. On specific phase (i.e., weeks 7- 10), swimmers completed 2 sets × 4 repetitions × 25-m with 60 seconds and 5 minutes of rest between repetitions and sets [23].

The specific kicking set was included in only EG (2 sessions in a week) immediately after the warm-up (i.e., 500 to 800-m of aerobic training [55% to 80% of maximum heart rate]) on Wednesdays and Fridays. On general phase (weeks 1-6), swimmers completed 3 sets × 6 repetitions × 50-m (i.e., 25-m kick, 25-m drills) with 60 seconds and 5 minutes of rest between repetitions and sets, respectively. On specific phase (weeks 7-10), swimmers completed 2 sets × 5 repetitions × 50-m with 90 seconds and 5 minutes of rest between repetitions and sets, respectively. The dry-land programme was applied by experienced strength and conditioning coaches included two sessions weekly. Each session started with a 15 minutes standard warm-up featuring dynamics stretching, functional and mobility and aerobic exercises. Subsequently, participants completed three lower body strength exercises targeting lower leg strength: BS, RLL, and SRDL, employing moderate contraction velocity and full range of motion. The BS exercise was executed at an intensity ranging from 60 to 85% of 1RM. The sets ranged from 2 to 3, and repetitions varied from 6 to 12 [23]. The SRDL was executed at an intensity ranging from 60 to 85% of 1RM. The sets ranged from 2 to 3, while the repetitions fluctuated between 6 and 10. The RLL comprised 6 to 8 sets of 6 to 12 repetitions. The resting period between sets and exercises was established at 2 minutes.

2.3.2. Testing Procedure

All the tests were performed within four consecutive days (standardized order): i) before the start of pre-season training; in day one, anthropometric and body composition (i.e., height,body mass, , fat mass), and all-out 200-m breaststroke swimming performance were conducted; ii) in day two, tethered swimming force was recorded with full breaststroke stroke / technique; iii) in day three, maximum muscle strength (1-RM back squat), and all-out 100-m breaststroke swimming performance were conducted; iv) in day four, AnCV (i.e., using performance times of 10, 15, and 25-m swim), and all-out 50-m breastroke swimming performance was carried out.

Anthropometry and body composition. Body mass,and body fat (%) were assessed using bioelectrical impedance analysis (BIA) using the Body Composition Analyzer: Inbody270 (Inbody270, Yi Hui Medical Co., Ltd, China).

Tethered force. A 30-second tethered swim test was conducted according to the method of Morouço et al. [24]. Briefly, each swimmer executed a maximum intensity breaststroke during all the effort. The measurement apparatus was a load-cell system attached to the swimmer, capturing data at 100 Hz with a capacity of 1.000 N. The maximal tethered swimming tests were conducted in radomized order using the complete breaststroke technique (i.e., upper and lower limbs movement). Continuous force data wascollected for 30 seconds at 100 Hz, and subjected to a 15 Hz cut-off digital filter (FIR - Window Blackman -61dB). The cut-off value was determined using Fast Fourier transformation to reduce artifact noise. The force variables derived from individual force-time curves were maximum force, mean force and fatigue index .

Muscular strength of the lower limbs. The maximum lower limb strength was assessed using the 1-RM of the BS (1-RM back squat). Swimmers performed a 3-minute warm-up, followed by 5 minutes of comprehensive static stretching. Subsequently, each swimmer executed one set of eight repetitions at 50% and one set of three repetitions at 70% of their projected 1RM back squat. The load was progressively augmented (i.e., 10 to 20%), with 2 to 3 repetitions and with a rest period of 2 to 4 minutes implemented. Subsequently, a minor increment in the load (i.e., 5%) and a rest period of 2 to 4 minutes were implemented to achieve the 1-RM back squat. The test concluded when the subjects were unable to execute two repetitions of BS, with the final successful attempt indicating the 1-RM back squat.

Anaerobic critical velocity. Anaerobic performance was assessed using method as proposed by Fernandes et al. [25]. AnCV was determined for each swimmer by utilizing the slope of the distance-time (Dd-t) relationship, plotting swimming performance times of 10, 15, and 25-m over time. The derived regression line equation is of the form y = ax + b, where "y" represents the distance swum, "x" denotes time, "a" signifies the AnCV (i.e., the slope in m/s), and "b" indicates the y-intercept value.

Swimming performance. The 50, 100 and 200-m race time of breaststroke block starting all-out performance were measured by a qualified timekeeper per stopwatch (SEIKO S120-4030, Tokyo, Japan) and registered in seconds. Three of the most frequently referenced kinematic parameters in breaststroke swimming biomechanics including SRSL, and SI were obtained together with time and average speed [15,20].

2.3.3. Monitoring of Training and Well-Being Status.

The training was monitored and quantified as the average training volume [3]. Additionally, individual biological responses to training were assessed using the modified relation between acute to chronic workload data (ACWR) [26]. The acute load refers to the mean training volume (measured in kilometers) during a period of one week, whereas the chronic training load represents the ongoing average training volume for each training macrocycle. The well-being status was utilized for daily monitoring of the recovery-stress state and an average weekly self-reported questionnaire employing

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a 7-point scale, which encompassed perceived levels of stress, fatigue, muscle soreness, and sleep quality. The aggregate of these four subjective ratings was reported as the Hooper index score (HI) [27].

2.4. Statistical Analyses

Randomization and allocation of participants to two groups were performed using the software SPSS version 26 (SPSS Inc., Chicago, IL, USA) and the lottery method. All data are presented as mean and standard deviation, mean difference, partial percentage difference, and 95% confidence intervals. Between-group differences at baseline were calculated using independent sample t-tests. The normality and sphericity of the data were assessed and validated using the Shapiro–Wilk and Mauchly tests, respectively. Repeated assessments ANOVA was employed to determine the differences between pre- and post-tests in the two groups (time factor) [15]. The effect size (ES) was evaluated by transforming partial Eta-squared into Cohen's d. Effect size (ES) was categorized as trivial ($d < 0.25$), small ($0.25 \leq d < 0.50$), moderate ($0.50 \leq d < 1$), and large ($d \geq 1$) [28].The statistical significance was established at $p < 0.05$.

3. Results

Similar baseline values were observed for anthropometric, breaststroke tethered swimming force (i.e., maximal force, mean force, fatigue index), maximum muscle strength (1-RM back squat), AnCV, swimming performance and technique (velocity, SR, SL, and SI) in 50, 100, and 200-m breaststroke swimming variables ($p > 0.05$). Descriptive statistics of average training volume, ACWR, HI, and each wellness status of young age-group swimmers through the 10-week (i.e., 6 weeks of general phase and 4 weeks of specific phase) of the first macrocycle of a traditional three-peak preparation program are presented in Table 1.

Table 1. Detailed description of average training volume, acute to chronic workload data (ACWR), Hooper index (HI), and each wellness status of 10-weeks for the Control Group (GC) and the Experimental Group (EG). Number of week (W).

Variables	Group	General phase							Specific phase				
		W1	**W2**	**W3**	**W4**	**W5**	**W6**	**Avg.**	**W7**	**W8**	**W9**	**W10**	**Avg.**
Total training volume (km)	CG	53.00	52.00	51.50	53.00	52.25	54.10	52.64	57.20	56.50	55.35	52.85	55.48
	EG	57.60	59.24	58.74	56.78	57.83	62.00	58.70	61.90	58.40	55.53	52.75	57.15
Average session trainingvolume (km)	CG	8.80	8.70	8.58	8.80	8.70	8.90	8.75	9.10	9.28	9.19	9.11	9.17
	EG	9.20	9.40	9.40	9.60	9.65	9.70	9.49	9.40	9.50	9.50	9.30	9.43
ACWR	CG	1.00	1.02	1.03	1.00	1.01	0.93	0.98	0.96	1.03	1.00	1.00	0.99
	EG	1.00	0.97	1.08	1.01	1.00	0.92	0.99	0.95	0.98	1.00	1.03	0.99
HI	CG	19.08	19.58	19.08	20.67	17.75	20.33	19.81	22.17	16.75	22.33	18.50	19.92
	EG	19.33	19.75	19.33	20.67	17.83	20.75	19.61	22.50	19.97	22.75	20.67	20.31
Fatigue	CG	5.34	4.96	5.63	5.48	4.33	5.66	5.23	5.58	4.00	5.33	5.12	5.01
	EG	5.33	5.03	5.70	5.52	4.33	5.67	5.26	5.76	5.20	5.38	5.79	5.23
Stress	CG	1.63	3.98	3.49	4.16	4.44	6.12	3.97	6.14	3.99	5.96	4.32	5.10
	EG	1.71	4.02	3.51	4.18	4.56	6.22	4.03	6.19	4.92	5.76	4.57	5.13
Muscle Soreness	CG	6.59	5.00	4.58	5.00	5.16	5.15	5.25	6.41	4.83	6.71	5.71	5.92
	EG	6.74	5.00	4.75	5.00	5.17	5.18	5.31	6.59	5.32	6.88	5.74	6.01
Sleep Quality	CG	5.49	5.67	5.31	6.03	3.85	3.41	4.96	4.03	3.86	4.34	3.39	3.91
	EG	5.51	5.67	5.35	5.97	3.82	3.59	4.99	3.97	4.53	4.77	3.22	3.94

Substantial improvements in tethered force, lower limbs strength, and AnCV were found in EG group while remained unchanged in CG group when comparing pre- and post- tests. The greatest improvements after the 10-weeks of concurrent resistance training (pool based + resistance workouts both in the pool and on dry land) were found in the mean force (30.04%, $p = 0.02$; $d = 0.75$; moderate), 1-RM back squat (20.57%, p = 0.01; d = 2.05, large), maximal force (19.23%, p = 0.03; d = 0.69, moderate), fatigue index (-10.83%, p = 0.77; d = 0.09, trivial), and AnCV (4.2%, p = 0.04; d = 0.61, moderate). The 100-m performance time was the most improved (-5.38%, p=0.01; d=0.90, moderate) followed by 50-m (-4.83, p=0.01; d=0.92, moderate) and 200-m (-4.28%, p=0.01; d=0.88, moderate) in the EG. However, the swimming techniques variables that could have potentially significant effects on swimming performance (i.e, SR, SL, and SI) yielded mixed results in both CG and EG group (Table 2)

Table 2. Changes in tethered force, lower limbs strength, anaerobic critical velocity and swimming performance and technique before and after 10-weeks of training for Control Group (GC) and Experimental Group (EG). Pre-test (PRE), post-test (POST). Confidence interval (CI). *,** p < 0.05, p = 0.01. .

Variables	Group	PRE	POST	p-value	95%CI (%Δ)	Effect size (d)
Swimming tethered force						
Maximal force (N)	CG	399.08±84.73	438.83±82.02	0.26	-109.18, 29.68 (9.96%)	0.35, small
	EG	406.08±116.57	484.17±31.50	0.03*	-147.52, -8.65 (19.23%)	0.69, moderate
Mean force (N)	CG	95.47±29.00	109.58±26.23	0.27	-39.65, 11.44 (14.78%)	0.33, small
	EG	103.97±44.50	135.27±18.65	0.02*	-56.85, -5.75 (30.04%)	0.75, moderate
Fatigue index (%)	CG	11.93±8.79	16.00±8.75	0.32	-12.24, 4.09 (34.12%)	0.30, small
	EG	10.71±13.55	9.55±7.55	0.77	-7.00, 9.33 (-10.83%)	0.09, trivial
Lower limbs strength						
1-RM back squat (kg)	CG	80.29±5.14	84.86±5.32	0.07	-9.48, 0.31 (5.69%)	0.50, moderate
	EG	80.42±5.33	96.96±6.95	0.01**	-21.43, -11.65 (20.57%)	2.05, large
Anaerobic critical velocity						
Anaerobic critical velocity (m/s)	CG	1.20±0.08	1.22±0.06	0.39	-0.08，0.03 (1.67%)	0.26, small
	EG	1.19±0.05	1.24±0.08	0.04*	-0.11，0.00 (4.2%)	0.61, moderate
Swimming performance and technique variables						
200-m performance (s)	CG	164.57± 5.43	161.57±6.70	0.21	-1.79, 7.79 (-1.82%)	0.38, small
	EG	165.58±6.86	158.33±6.16	0.01**	2.13, 11.70 (-4.38%)	0.88, moderate
Stoke rate (cycles/s)	CG	32.27±2.00	34.14±1.93	0.03*	-3.54, -0.20 (5.79%)	0.68, moderate
	EG	31.80±2.32	34.96±1.85	0.01**	-4.83, -1.49 (9.94%)	1.15, large
Stroke length (m)	CG	2.27±0.08	2.18±0.06	0.01**	0.02, 0.15 (-3.96%)	0.82, moderate
	EG	2.29±0.09	2.17±0.07	0.01**	0.06, 0.18 (-5.24%)	1.18, large
Stroke index (m²/s)	CG	2.76±0.03	2.70±0.11	0.06	-0.01, 0.11 (-2.17%)	0.57, moderate
	EG	2.76±0.04	2.73±0.05	0.24	-0.02, 0.09 (-1.09%)	0.36, small
100-m performance (s)	CG	74.82±4.33	71.87±1.16	0.02*	0.46, 5.45 (-3.94%)	0.72, moderate
	EG	75.47±2.66	71.41±3.12	0.01**	1.56, 6.56 (-5.38%)	0.90, moderate
Stoke rate (cycles/s)	CG	44.57±0.87	45.36±1.50	0.25	-2.15, 0.58 (2.29%)	0.35, small
	EG	44.07±0.30	35.88±2.81	0.01**	-3.20, -0.44 (5.31%)	0.8, moderate
Stroke length (m)	CG	2.33±0.11	2.37±0.07	0.31	-0.11, 0.04 (1.72%)	0.31, small
	EG	2.34±0.08	2.35±0.10	0.66	-0.09, 0.06 (0.43%)	0.14, trivial
Stroke index (m²/s)	CG	3.12±0.29	3.29±0.09	0.04	-0.33, -0.01 (5.45%)	0.63, moderate
	EG	3.10±0.21	3.30±0.13	0.02*	-0.36, -0.03 (6.45%)	0.73, moderate
50-m performance (s)	CG	35.69±1.55	34.56±1.16	0.05	0.01, 2.25 (-3.17%)	0.61, moderate
	EG	35.18±1.46	33.48±1.33	0.01**	0.59, 2.83 (-4.83%)	0.92, moderate
Stoke rate (cycles/s)	CG	58.93±0.60	59.53±1.92	0.32	-1.80, 0.60 (1.54%)	0.31, small
	EG	59.56±2.07	59.72±0.41	0.78	-1.37, 1.80 (0.4%)	0.09, trivial
Stroke length (m)	CG	2.16±0.10	2.20±0.10	0.33	-0.11, 0.40 (1.85%)	0.29, small
	EG	2.16±0.10	2.26±0.90	0.02*	-0.18, -0.02 (4.63%)	0.75, moderate
Stroke index (m²/s)	CG	3.04±0.26	3.19±0.20	0.12	-0.34, 0.04 (4.93%)	0.48, small
	EG	3.07±0.20	3.28±0.26	0.01**	-0.49, -0.11 (6.84%)	0.96, moderate

Considering the difference between the CG and the EG after 10-weeks of training (Table 3), the EG demonstrated a significant improvement in mean tethered force (23.44%, p = 0.04; d = 0.61, moderate) and 1-RM back squat strength (14.23%, p = 0.01; d = 0.75, moderate). In terms of swimming performance, the EG showed significant improvements in 50-m swimming velocity (3.45%, p = 0.02; d = 0.59, moderate) and 200-m time (1.79%, p = 0.05; d = 0.50, moderate). Additionally, the SI for 50-m in the EG was higher than in the CG (5.96%, p = 0.03; d = 0.54, moderate).

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Table 3. Changes in tethered force, lower limbs strength, anaerobic critical velocity and swimming performance and technique after 10-weeks of training between groups. Control Group (GC) and the Experimental Group (EG). Confidence interval (CI). *,** p ≤ 0.05, p = 0.01. .

Variables	CG	EG	p-value	95%CI (%Δ)	Effect size (d)
Swimming tethered force					
Maximal force (N)	438.83±82.02	484.17±31.5	0.20	-114.77，24.10 (10.33%)	0.40, small
Mean force (N)	109.58±26.23	135.27±18.65	0.04*	-51.25，-0.15 (23.44%)	0.61, moderate
Fatigue index (%)	16.00±8.75	10.55±7.55	0.12	-1.71, 14.63 (34.10%)	0.48, small
Lower limbs strength					
1-RM back squat (kg)	84.88±5.32	96.96±6.95	0.01**	-16.98, -7.19 (14.23%)	0.75, moderate
Anaerobic critical velocity					
Anaerobic critical velocity (m/s)	1.22±0.06	1.24±0.08	0.58	-0.07，0.04 (1.64%)	0.084, trivial
Swimming Performance and technique variables					
50-m time (s)	34.56±1.16	33.48±1.33	0.45	-1.76, 3.92 (-3.12%)	0.19, trivial
100-m time (s)	71.87±1.56	71.41±3.12	0.75	-2.39, 3.30 (0.64%)	0.09, trivial
200-m time (s)	161.57±6.71	158.67±3.70	0.05*	0.06, 5.74 (1.79%)	0.50, moderate
50-m velocity (m/s)	1.45±0.05	1.50±0.06	0.02*	-0.09, -0.01 (3.45%)	0.59, moderate
100-m velocity (m/s)	1.39±0.02	1.40±0.06	0.56	-0.05, 0.03 (0.72%)	0.14, trivial
200-m velocity (m/s)	1.24±0.05	1.26±0.03	0.29	-0.06, 0.02 (1.61%)	0.26, small
50-m stroke index-(m^2/s)	3.19±0.20	3.38±0.26	0.03*	-0.36, -0.02 (5.96%)	0.54, moderate
100-m stroke index (m^2/s)	3.29±0.09	3.30±0.13	0.95	-0.17,0.16 (0.30%)	0.06, trivial
200-m stroke index-(m^2/s)	2.7±0.11	2.73±0.05	0.30	-0.08, 0.03 (1.11%)	0.32, small
50-m stroke rate-(cycle/s)	59.54±1.92	59.72±0.41	0.69	-1.10, 0.73 (-0.46)	0.11, trivial
100-m stroke rate-(cycle/s)	45.36±1.50	45.88±2.81	0.45	-1.89, 0.85 (1.47%)	0.23, trivial
200-m stroke rate-(cycle/s)	34.14±1.93	34.96±1.85	0.33	-2.49, 0.85 (2.40%)	0.30, small
50-m stroke length (m)	2.20±0.73	2.26±0.09	0.11	-0.13, 0.01 (2.73%)	0.40, small
100-m stroke length-(m)	2.37±0.07	2.35±0.10	0.74	-0.06, 0.09 (-0.84%)	0.11, trivial
200-m stroke length (m)	2.18±0.06	2.17±0.07	0.67	-0.06, 0.08 (-0.46%)	0.13, trivial

4. Discussion

This study aimed to evaluate the effects of a 10-week concurrent resistance training program, i.e., incorporating both aquatic and dry-land exercises, on tethered force, lower limb strength, AnCV, and swimming performance in regional age-group breaststroke swimmers. Overall, there were significant improvement in swimming tethered force (i.e., mean force and maximal force), lower limbs strength (1-RM back squat), AnCV and 50-100-200-m breaststroke swimming performance in the EG compared to CG after 10-weeks of concurrent resistance training which combined aquatics resistance with parachute, fins, hand paddles and specific kicking set and dry-land (i.e., BS, RLL, and SRDL). Our results suggest effectiveness of a concurrent resistance training program of combined pool based + resistance workouts both in the pool (using a parachute, fins, hand paddles, and specific kicking sets) and on dry land (which included BS, RLL, and SRDL), which agrees with previous studies in front-crawl [23] and butterfly swimming [15] in age-group swimmers.

Currently, monitoring the association and interaction of internal loads with psychological and physical well-being is a key issue when monitoring athletes [3]. In the present study, the average total weekly training load in the general phase (9.49 km) and in the specific phase (9.43 km) were higher than those reported most other studies [29,30] in age-group swimmers. One possible reason for this difference is that the first macrocycle of training at the start of the season needs to focus on building aerobic endurance up to the lactate threshold along with strength and conditioning. This is because the main goal of endurance training is to make physiological, psychological, and technical changes that set the stage for age-group swimmers' competitive performances [31,32]. However, the training volume of the current study in both general and specific phases are consistent with elite swimmers [31].

The ACWR observed in the current study (ratio ~0.9 -1.0) suggests that the training progression was effective while balancing training loads and enhancing performance, and consistent with previous results (ratio between 0.8 and 1.3). This ratio isoften considered a "safe zone," where the workload is balanced, and the risk of injury is relatively low in age-group swimmers [26]. Interesting, the HI score showed low variability during the general and specific training periods, suggesting that the structured resistance training program carried out together with the pool training program did not have a negative effect on adaptability, homeostasis restoration, or ever well-being status.

Upon evaluating changes and enhancements after a 10-week program integrating aquatic resistance and dry-land training, the most notable finding from the data analysis was the increment in mean force of the 30 seconds tethered force, following by the 1-RM back squat, maximal force, fatigue index, and AnCV, respectively. These changes are in line with previous studies [9,17]. Also, the EG enhanced their tethered mean force by 30% and their maximal force by 19% by the utilization of aquatic resistance apparatus. Besides, concurrent aquatic and lower limb dry-land resistance training improved the fatigue index in the experimental group, indicating that the training enhances both muscular strength and endurance. For the perspective of lower limbs strength improvement, combined aquatics and dry-land resistance training with the intensity between 60 and 85% of 1RM, resulted in an increase of ~20% on the1RM back squat, slightly higher than the values reported before in the national competitive freestyle swimmers (~15%) [23], but lower than the observed for age-group butterfly swimmers (22%) after 8-weeks of combining high intensity interval training and maximum strength training [15].

Remarkably, the performance in the 50, 100, and 200-m breaststroke time improved by 4.38, 5.38, and 4.83%, underlining that the 10weeks program integrating dry-land training with aquatic resistance training can improve breaststroke performance from sprint to middle distances. Our results in breaststroke showed similar improvements to those reported for100-m freestyle (4.4%) [23] and 100-m butterfly (3.6%) [15] in age-group swimmers. The neuromuscular adaptations resulting from the integration of aquatic and dry-land resistance training over a 10-week period, along with the quantity and quality of training, may enhance the specificity of adaptations during both general and specific phases. This transfer of enhanced strength could serve as indirect evidence supporting the observed improvements in swimming performance over distances ranging from 50 to 200-m. In addition, swimming efficiency (i.e., Stroke index - SI) enhanced by 6.5% in the 50-m and 6.8% in the 100-m within the experimental group. This enhancement may result from the increase in maximum lower limb muscle strength and endurance. The transfer of force gain from the lower limb to the mean tethered force was significantly greater in the EG (135 N) compared to the CG (110 N), demonstrating a 23% difference. This highlights the efficacy of integrating aquatic resistance with parachutes, fins, hand paddles, and specific kicking sets, along with dry-land training, in enhancing swimming efficiency, particularly in sprint distances (50-100-m) [24].

Nonetheless, it is crucial to recognize specific shortcomings and possible limitations of our study. Firstly, the influence of concurrent resistance training on physiological variables, such as anaerobic threshold , maximal oxygen uptake , metabolic power and energy cost werenot considered due to logistic issues. Secondly, it is important to acknowledge that the findings of the present study are applicable specifically to the young regional age-group swimmers and should not be extrapolated to other levels of swimming performance, i.e., swimmers with varying performance levels compared to the regional age-group swimmers in the current study, such as young elite and elite swimmers, may exhibit contradictory outcomes. Third, a study with an intervention that did not complete the full periodization cycle has notable limitations, such as incomplete adaptations, inaccurate performance measurements, and the inability to generalize results to long-term training scenarios. However, despite these limitations, the results confirmed the importance of this type of training to improve performance in age-groups breaststroke swimmers and, therefore, emphasizing the importance of its implementation in training programmes.

5. Conclusions

Combining pool based + resistance workouts both in the pool (using a parachute, fins, hand paddles, and specific kicking sets) and on dry land (which in-cluded BS, RLL, and SRDL) is a valuable approach to enhance breaststroke swimming performance. Although previous studies have reported the beneficial effects of resistance training both in and out of the water—and the results are even better when these two approaches are combined—many coaches worldwide still do not give these workouts the attention they deserve. Considering that swimming competitions today are highly demanding, with heats, semifinals, and finals, achieving full physical fitness to swim at a high level in each phase is crucial to a swimmer's success.

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Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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