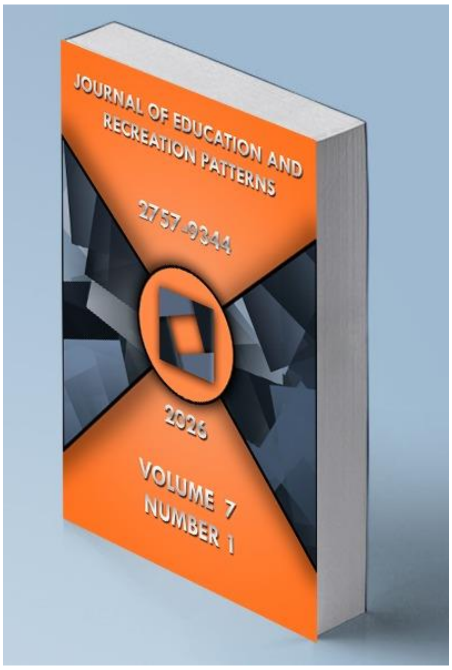

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ABSTRACT

This study examined an 8-week in-season low-volume, high-velocity dry-land strength and plyometric program on sprint swimming and associated fitness in competitive swimmers. In a randomized controlled pre–post design, 48 swimmers aged 13–18 years were assigned to an experimental group (EG; n = 24), performing dry-land strength training twice weekly alongside swim training, or a control group (CG; n = 24) continuing swim training only. The program comprised upper- and lower-body exercises at 40–65% one-repetition maximum with maximal concentric velocity. Outcomes—50-m freestyle time, countermovement jump (CMJ) height, pull-up repetitions, medicine ball chest throw distance, and 15-m start time—were assessed pre- and post-intervention. A 2 × 2 mixed-model ANOVA revealed significant Group × Time interactions for all variables (all $p \leq .002$). The EG improved significantly in 50-m freestyle time (Δ = −3.95%, g = 0.45), CMJ height (Δ = +13.18%, g = 0.76), pull-up repetitions (Δ = +77.59%, g = 1.18), medicine ball throw (Δ = +9.68%, g = 0.81), and 15-m start time (Δ = −4.21%, g = 0.63), whereas the CG showed no significant change (all $p > .05$). Within the EG, changes in CMJ (r = −.61), pull-ups (r = −.58), medicine ball throw (r = −.44), and 15-m start (r = .67) were significantly associated with changes in 50-m time (all $p < .05$). Twice-weekly low-volume, high-velocity dry-land training is associated with improved sprint swimming, explosive power, and start efficiency in adolescent swimmers. Because neuromuscular function and stroke mechanics were not measured, mechanisms remain unconfirmed.

Keywords: Adolescent Swimmers, Countermovement Jump, Resistance Training, Sprint Swimming, Swim Start.

INTRODUCTION

Swimming is among the most physiologically and biomechanically demanding Olympic sports, encompassing 37 individual disciplines ranging from 50 to 1500 meters. Performance in competitive swimming is determined by a complex interaction of anthropometric, physiological, biomechanical, and neuromuscular factors (Lätt et al., 2010; Barbosa et al., 2015). Although aerobic capacity constitutes a foundational component of swimmer preparation, the majority of Olympic-level events contested over 200 meters or less are completed in under 140 seconds, placing considerable demands on anaerobic energy systems, muscular strength, and explosive power output (Nugent et al., 2017a; Chortane et al., 2022).

The training paradigm of competitive swimming has historically been dominated by high-volume, low-intensity approaches, with weekly training distances frequently exceeding 60,000–80,000 meters. However, the scientific evidence supporting the superiority of high-volume training over alternative approaches remains equivocal (Kilen et al., 2014). Chortane et al. (2022) demonstrated that a sudden increase in training volume over four weeks significantly elevated somatic and cognitive anxiety while reducing self-confidence in competitive adolescent swimmers, without producing meaningful improvements in 50-meter sprint performance. In contrast, a systematic review by Nugent et al. (2017a) identified that six of seven controlled HIT intervention studies reported significant improvements in physiological performance, and four reported significant improvements in competitive swimming performance across distances ranging from 50 to 2000 meters, with none resulting in performance decrements. Nurmukhanbetova et al. (2023) applied a low-volume, high-intensity training method to elite youth swimmers over five months and reported meaningful improvements in upper-body power (16.80%), upper-body speed (13.48%), and swimming stroke efficiency (40.71%) in the experimental group, alongside improvements in expert-rated technical skills. Kilen et al. (2014) confirmed that a 50% reduction in training volume combined with a doubling of high-intensity work over 12 weeks neither improved nor compromised performance in elite swimmers, demonstrating that large reductions in training distance can be sustained without performance loss.

Alongside aerobic conditioning, dry-land strength and power training has emerged as a critical component of comprehensive swimmer preparation, particularly for sprint-oriented events. Keiner et al. (2021) demonstrated that maximum strength in the back squat and bench press explained 50–65% of variance in swimming power output and start performance, and 45–62% of variance in 50-meter and 100-meter freestyle race times in competitive youth swimmers. The importance of lower-body maximum strength for swim start performance has been documented across multiple populations. García-Ramos et al. (2016b) found that peak bar velocity during loaded squat jumps was the variable most strongly correlated with start times at 5, 10, and 15 meters in international-level female swimmers, while isometric knee extension tests showed no significant correlation with start performance, highlighting the necessity of dynamic strength assessment. Similarly, Zebura et al. (2023) reported that 1RM back squat, countermovement jump, and squat jump performance collectively explained 55–73% of variance in swim start performance up to 15 meters in German youth elite swimmers, with CMJ demonstrating the strongest individual correlation ($r = -0.858$, $p < 0.01$).

Marques et al. (2020) examined the effects of a 20-week in-season combined strength and plyometrics program in elite junior swimmers using low loads, low volume, and maximal execution velocities. The intervention produced significant improvements in CMJ height (12.1%), estimated 1RM in squat (16.4%) and bench press (12.1%), and 50-meter freestyle time (−3.9%), with relative changes in squat strength and pull-up performance significantly correlated with sprint swimming improvements. These findings provide direct evidence of functional transfer from land-based strength gains to in-water sprint output. Biomechanical parameters also play a primary role in determining competitive performance. Lätt et al. (2010) demonstrated that stroke index and stroke rate collectively explained 92.6% of variance in 100-meter front crawl performance in adolescent swimmers, reinforcing the importance of technical efficiency. Barbosa et al. (2015) further established a cubed mathematical relationship between swimming power output and sprint performance in 100 young swimmers ($R^2 = 0.426$, $p < 0.001$), confirming that power production capacity is a fundamental determinant of competitive speed.

Despite growing evidence supporting both HIT approaches and strength training for swimmers, few intervention studies have simultaneously assessed changes in sprint swimming performance, land-based maximal strength, and swim start performance within the same experimental design, particularly in young elite populations. Conceptually, the present study is grounded in the principles of training specificity and dynamic correspondence, which hold that the transfer of resistance training to a target skill depends on the correspondence between the training stimulus and the velocity, force, and neuromuscular demands of that skill (Crowley et al., 2017). Within this framework, low-volume, high-velocity dry-land training is proposed to enhance neuromuscular power and rapid force production, which in turn may improve swim-start performance and propulsive capacity and, ultimately, translate into faster 50-m freestyle times. This proposed pathway — low-volume, high-velocity dry-land training → improved neuromuscular power and force production → improved start performance and propulsive capacity → improved 50-m freestyle performance — also intersects with the concept of adolescent trainability, given that the neuromuscular adaptations targeted here are considered particularly responsive during the developmental years sampled in this study. The purpose of the present study was therefore to investigate the effects of an 8-week low-volume, high-velocity land-based strength training program combined with standard aquatic training on 50-meter sprint swimming performance, upper and lower limb maximal strength, and swim start performance in young competitive swimmers. It was hypothesized that the combined intervention would produce significant improvements in all measured outcomes relative to a control group receiving aquatic training alone, and that changes in land-based strength parameters would be significantly correlated with changes in sprint swimming and start performance. The novelty of the present study lies in combining, within a single randomized controlled design, an adolescent sample (aged 13–18 years), an 8-week in-season intervention, and the simultaneous assessment of dry-land power, swim-start, and sprint swimming outcomes together with an analysis of their interrelationships — a combination that, to our knowledge, has not previously been examined in this population.

METHOD

Study Design

A randomized controlled pre-test–post-test design was employed over an 8-week in-season period. After baseline testing, participants were randomly assigned in a 1:1 ratio to either the EG, which completed a supervised dry-land strength training program twice weekly in addition to their regular swim training, or the CG, which continued with their regular swim training only. Randomization was performed using a computer-generated randomization sequence; simple randomization was applied without stratification, ensuring an equal probability of assignment to each group. The allocation sequence was concealed from the performance assessors until group assignment had been completed. Performance assessors were blinded to group allocation; owing to the nature of the intervention, participants and coaches could not be blinded. All 48 randomized swimmers (24 per group) completed the intervention and post-intervention testing, with no dropouts or loss to follow-up, so the analysed sample was identical to the randomized sample. No training-related adverse events or injuries were reported during the intervention. Performance assessments were conducted at baseline (Week 0) and immediately following the intervention (Week 8).

Participants

Based on a power analysis using the effect size observed for 50-m freestyle performance in comparable research (ES ≈ 0.45; Marques et al., 2020), with an alpha level of .05 and a power of .80, a minimum sample of 41 participants was determined to be necessary for adequate statistical power. Accounting for an estimated 15% attrition rate, a total of 48 licensed competitive swimmers (aged 13–18 years) were recruited to participate in this study and assigned to either an experimental group (EG; n = 24) or a control group (CG; n = 24). The sample included both male and female athletes, with a slightly higher proportion of male swimmers across both groups; the experimental and control groups were comparable in sex distribution, with no meaningful imbalance between them. All participants were licensed competitive club swimmers with at least two years of structured training experience. Biological maturation was not formally assessed in the present study; this is acknowledged as a limitation, given that maturity status may influence strength and power adaptations in adolescents. Participants' stroke specialization, weekly swimming volume, and prior structured strength-training experience are summarized in Table 2. Inclusion criteria were at least two years of competitive swimming experience, no musculoskeletal injury within the preceding three months, and active participation in a licensed club. Exclusion criteria were concurrent participation in any supplementary strength training program outside the scope of this study. All participants provided written assent and their parents or legal guardians provided written informed consent prior to enrollment. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Trakya University Faculty of Medicine Non-interventional Scientific Research Ethics Committee (TÜTF-GOBAEK; approval number 2026/220; approval date 04 May 2026). Confidentiality of participant data was maintained throughout, and risk and adverse-event monitoring procedures were implemented during all training and testing sessions.

Testing Procedures

All testing sessions were conducted in the afternoon under standardized environmental conditions (~22–24°C; ~55–65% relative humidity), following at least 48 hours free from fatiguing training. Strong verbal encouragement was provided throughout all tests to ensure maximal effort.

Primary Outcome: 50-m Freestyle Swimming Time

Following a standardized in-water warm-up of approximately 1,000 m (Neiva et al., 2014), swimmers rested for approximately 5 minutes before performing two maximal 50-m front crawl time trials, separated by 10 minutes of passive recovery. Trials were conducted in a 25-m indoor pool (~27.5°C). Race time was measured manually from the starting signal until the swimmer touched the wall, using calibrated stopwatches (Finis 3×100, Livermore, CA), with two experienced timekeepers timing each trial independently and the mean of the two recorded per trial. Because two independent timekeepers were used, their values were averaged to reduce individual timing error, and the mean of the two trials was retained for analysis. This manual protocol has previously demonstrated acceptable reliability (CV = 4.3%; ICC = 0.96, 95% CI: 0.93–0.99; Marques et al., 2020); the precision limits of manual timing relative to electronic timing are acknowledged in the Limitations section.

Countermovement Jump (CMJ)

Vertical jump height was assessed using a countermovement jump protocol on an infrared contact mat system (Optojump, Microgate, Bolzano, Italy). Participants stood upright with hands on hips to eliminate the influence of arm swing. Following a standardized warm-up (2 sets of 10 bodyweight squats and 5 submaximal CMJs), each participant performed three maximal CMJs, with one minute of rest between attempts. The highest and lowest values were discarded, and the middle value was retained for analysis. The CMJ demonstrates high test-retest reliability (CV = 2.4%; ICC = 0.99, 95% CI: 0.98–1.00; Marques et al., 2020). The validity of jump height assessed via infrared timing systems has been established in previous research (Glatthorn et al., 2011).

Pull-Up Test (PU)

Upper body muscular endurance was assessed via a maximum-repetition pull-up test, following the protocol described by Sanchez-Moreno et al. (2017). Participants began from a dead-hang position with a self-selected pronated grip (approximately 150% of biacromial width) and performed repetitions until failure, defined as the inability to raise the chin above the bar or a pause of more than 2–3 seconds in the starting position. Each concentric phase was performed at maximal intended velocity following a 1-second static pause at the bottom position; movement velocity was verbally instructed and visually monitored rather than objectively measured with a velocity transducer. The eccentric phase was controlled. The same grip width was recorded and replicated across all testing sessions. Warm-up consisted of 5 minutes of upper limb joint mobility exercises and 1 set of 2–5 submaximal pull-up repetitions.

Medicine Ball Chest Throw (MBCT)

Upper limb explosive power was assessed using a 3-kg medicine ball chest throw, as recommended for athletic populations (Stockbrugger & Haennel, 2001). Participants were seated with their back flat against a wall and threw the ball as far as possible using a two-handed push action. Three trials were performed with 90 seconds of recovery, and the best distance (measured in centimeters from the release point to the landing point) was retained. This test has shown strong convergent validity with upper-body power assessments and acceptable test-retest reliability (ICC = 0.97; Clemons et al., 2010).

15-m Start Time

Sprint start performance was assessed by recording the time elapsed from the starting signal to the moment the swimmer's body crossed the 15-m mark (Tor et al., 2015). Timing was initiated by the starting signal and measured using a dual-beam photocell gate system (Brower Timing, Draper, UT) positioned at 15 m from the starting block. Two trials were performed with 5 minutes of passive recovery. The mean of the two trials was used for analysis. The 15-m start time is considered a valid indicator of explosive swim start performance (West et al., 2011) and has demonstrated high reliability in competitive swimmers (ICC = 0.96; García-Ramos et al., 2016a).

Training Program

The EG completed a combined dry-land strength and plyometric training program twice per week (Monday and Thursday) on non-consecutive days over 8 weeks, in addition to their regular swim training schedule (5–6 sessions per week). All strength training sessions were conducted in the afternoon, prior to swimming practice, lasted approximately 60–70 minutes, and were directly supervised by the research team. All experimental-group participants completed the 8-week program with no dropouts, and session attendance was monitored throughout. Training loads were individualized based on estimated one-repetition maximum (1RM) values derived from a progressive isoinertial loading test (Sánchez-Medina et al., 2017), consistent with the approach described by Marques et al. (2020). Exercises included upper and lower body movements (full squat, squat jump, countermovement jump, bench press, pull-ups, shoulder press). All concentric phases were performed at maximal intended velocity with low-to-moderate loads (40–65% 1RM) and low volume (3–4 sets of 4–10 repetitions), following the principles established by Marques et al. (2020); movement velocity was verbally encouraged and visually monitored rather than measured with a velocity-based training device. The complete session structure, including exercises, sets, repetitions, load progression, and rest intervals across the 8-week program, is presented in Table 1. To equate swimming training load between conditions, both the EG and the CG followed the same club swimming programme (5–6 sessions per week) throughout the intervention, so that the two groups differed only in the supplementary dry-land program. No formal taper occurred during the intervention period, and the competition schedule was comparable across groups. Objective in-water workload (e.g., weekly distance in kilometres and session-RPE) was not quantified, which is noted as a limitation. The CG maintained their regular swimming training without any supplementary dry-land strength training.

Table 1

Structure of the 8-Week Low-Volume, High-Velocity Dry-Land Strength and Plyometric Training Program

Exercise	Sets × Reps	Load (% 1RM)	Inter-set rest	Concentric execution
Full squat	3–4 × 4–8	40–65	2–3 min	Maximal intended velocity
Bench press	3–4 × 4–8	40–65	2–3 min	Maximal intended velocity
Shoulder press	3 × 6–10	40–65	2 min	Maximal intended velocity
Pull-up	3 × 4–10	Body mass (assisted/loaded as required)	2–3 min	Maximal intended velocity (concentric), controlled eccentric
Squat jump	3 × 4–6	Body mass	2–3 min	Maximal intended velocity
Countermovement jump	3 × 4–6	Body mass	2 min	Maximal intended velocity

Note. 1RM = one-repetition maximum. The program was performed twice per week (Monday and Thursday) on non-consecutive days for 8 weeks, in the afternoon prior to swimming practice, with each session lasting approximately 60–70 min and directly supervised. Each session began with a standardized warm-up (joint mobility and 1–2 submaximal sets per exercise) and finished with a brief cool-down. Loads were individualized from a progressive isoinertial loading test and progressed from the lower toward the upper end of the prescribed load range across the 8 weeks. All concentric actions were executed at maximal intended velocity; velocity was verbally encouraged and visually monitored rather than measured with a velocity transducer. All experimental-group participants completed the program, and session attendance was monitored throughout.

Statistical Analysis

Data normality was assessed using the Shapiro-Wilk test, and homogeneity of variance was verified with Levene's test; all outcome variables satisfied the assumptions of normality and homogeneity of variance (all $p > .05$). Group differences at baseline were examined using independent samples t-tests. A 2 (group: EG vs. CG) × 2 (time: pre vs. post) mixed-model ANOVA was used to evaluate the training effects on each outcome variable, with partial eta-squared (η^2p) reported as the effect size for the interaction. Significant interactions were followed up with paired-samples t-tests, and within-group effect sizes were calculated using Hedges' g, and interpreted using thresholds of 0.20, 0.60, 1.20, and 2.00 for small, moderate, large, and very large effects, respectively (Hopkins et al., 2009). Because multiple outcomes and post hoc comparisons were tested, the potential for Type I error inflation was acknowledged; no formal correction for multiple comparisons was applied, given the small number of pre-planned outcomes and the confirmatory focus on the Group × Time interactions, and the within-group comparisons should be interpreted with this in mind. Pearson product-moment correlation coefficients were used to examine relationships between changes in dry-land performance and changes in swimming performance; because these analyses were restricted to the experimental group (n = 24), they are reported and interpreted as exploratory. To aid interpretation, 95% confidence intervals were reported for the correlation coefficients (Table 6). Statistical significance was set at $p < .05$. All analyses were conducted using SPSS version 27.0 (IBM Corp., Armonk, NY).

FINDINGS

Prior to examining intervention effects, baseline equivalence between the experimental group (EG, n = 24) and the control group (CG, n = 24) was evaluated using independent samples t-tests. As presented in Table 2, no statistically significant differences were observed between groups on any demographic or performance variable at baseline (all $p > .05$, all Cohen's $d < 0.15$). Groups were comparable in age ($t(46) = −0.46$, $p = .646$, $d = 0.13$), body mass ($t(46) = 0.21$, $p = .835$, $d = 0.06$), height ($t(46) = 0.48$, $p = .634$, $d = 0.13$), and training experience ($t(46) = 0.39$, $p = .698$, $d = 0.11$). All baseline performance measures — including 50-m freestyle time, countermovement jump (CMJ) height, pull-up repetitions, medicine ball (MB) throw distance, and 15-m start time — were also statistically equivalent between groups, indicating that any post-intervention differences were unlikely to be explained by pre-existing performance disparities.

Table 2

Baseline Descriptive Characteristics of Experimental and Control Groups

Variable	EG (n = 24)		CG (n = 24)		*t*	*p*	*d*
	M	SD	*M*	SD			
Age (years)	15.4	1.6	15.6	1.5	−0.46	.646	0.13
Body mass (kg)	58.3	7.1	57.9	6.8	0.21	.835	0.06
Height (m)	1.68	0.07	1.67	0.08	0.48	.634	0.13
Training experience (years)	4.9	1.8	4.7	1.9	0.39	.698	0.11
50-m freestyle (s)	32.14	2.89	32.41	2.74	−0.34	.734	0.10
CMJ (cm)	29.6	5.2	30.1	5.4	−0.33	.742	0.09
Pull-up (reps)	5.8	3.4	6.1	3.6	−0.31	.760	0.08
MB throw (cm)	348.2	42.6	351.7	44.1	−0.29	.775	0.08
15-m start (s)	7.84	0.54	7.88	0.51	−0.27	.789	0.08

Note. EG = experimental group; CG = control group; CMJ = countermovement jump; MB throw = medicine ball chest throw; 15-m start = 15-m start time. No statistically significant between-group differences were observed at baseline (all $p > .05$). Effect sizes are Cohen's d.

Descriptive statistics for all outcome variables at pre- and post-test are presented in Table 3. A clear pattern of improvement was evident in the EG across all five measures, whereas CG values remained largely unchanged over the 8-week period. In the EG, the largest absolute improvement was recorded for pull-up performance, which increased from 5.8 ± 3.4 repetitions at pre-test to 10.3 ± 4.1 repetitions at post-test. CMJ height increased from 29.6 ± 5.2 cm to 33.5 ± 5.1 cm, and MB throw distance improved from 348.2 ± 42.6 cm to 381.9 ± 40.8 cm. The 50-m freestyle time was reduced from 32.14 ± 2.89 s to 30.87 ± 2.71 s, and the 15-m start time improved from 7.84 ± 0.54 s to 7.51 ± 0.49 s. In contrast, post-training values in the CG remained highly comparable to baseline across all variables, suggesting that regular swim training alone was insufficient to produce meaningful adaptation in the assessed performance indices over the same period.

Table 3

Pre- and Post-Training Descriptive Statistics for All Outcome Variables by Group

Variable	EG (n = 24)				CG (n = 24)			
	Pre M	Pre SD	*Post M*	Post SD	*Pre M*	Pre SD	*Post M*	Post SD
50-m freestyle (s)	32.14	2.89	30.87	2.71	32.41	2.74	32.18	2.70
CMJ (cm)	29.6	5.2	33.5	5.1	30.1	5.4	30.4	5.3
Pull-up (reps)	5.8	3.4	10.3	4.1	6.1	3.6	6.4	3.5
MB throw (cm)	348.2	42.6	381.9	40.8	351.7	44.1	353.2	43.6
15-m start (s)	7.84	0.54	7.51	0.49	7.88	0.51	7.85	0.52

Note. EG = experimental group; CG = control group; CMJ = countermovement jump; MB throw = medicine ball chest throw; 15-m start = 15-m start time. Pre = baseline (Week 0); Post = post-intervention (Week 8). Values are means ± standard deviations.

To evaluate the training effects of the 8-week in-season dry-land strength and plyometric program, a series of 2 (Group: EG vs. CG) × 2 (Time: Pre vs. Post) mixed-model ANOVAs were conducted, with group as the between-subjects factor and time as the within-subjects factor. As shown in Table 4, significant Group × Time interaction effects were identified for all five outcome variables (all $p \leq .002$), confirming that the pattern of change over time differed systematically between groups. The largest interaction effect was observed for pull-up performance ($\eta 2p = .308$, $F(1, 46) = 20.46$, $p < .001$), followed by CMJ height ($\eta 2p = .280$, $F(1, 46) = 17.93$, $p < .001$), 50-m freestyle time ($\eta 2p = .237$, $F(1, 46) = 14.27$, $p < .001$), MB throw distance ($\eta 2p = .231$, $F(1, 46) = 13.85$, $p < .001$), and 15-m start time ($\eta 2p = .183$, $F(1, 46) = 10.31$, $p = .002$). Between-group main effects were non-significant for all variables (all $p > .05$), consistent with established baseline equivalence. Significant main effects for Time were observed across all outcomes (all $p \leq .001$); however, these are most meaningfully interpreted in light of the significant Group × Time interactions.

Table 4

Results of 2 (Group) × 2 (Time) Mixed-Model ANOVA for All Outcome Variables

Variable and effect	Effect	*F*	*df*	*p*	η^2p
50-m freestyle (s)					
Group	Between	0.12	1, 46	.731	.003
Time	Within	18.34	1, 46	<.001	.285
Group × Time	Interaction	14.27	1, 46	<.001	.237
CMJ (cm)					
Group	Between	0.09	1, 46	.762	.002
Time	Within	21.58	1, 46	<.001	.319
Group × Time	Interaction	17.93	1, 46	<.001	.280
Pull-up (reps)					
Group	Between	0.07	1, 46	.793	.002

Time	Within	24.11	1, 46	<.001	.344
Group × Time	Interaction	20.46	1, 46	<.001	.308
MB throw (cm)					
Group	Between	0.06	1, 46	.806	.001
Time	Within	16.72	1, 46	<.001	.267
Group × Time	Interaction	13.85	1, 46	<.001	.231
15-m start (s)					
Group	Between	0.07	1, 46	.793	.002
Time	Within	12.48	1, 46	.001	.213
Group × Time	Interaction	10.31	1, 46	.002	.183

Note. CMJ = countermovement jump; MB throw = medicine ball chest throw; 15-m start = 15-m start time. η^2p = partial eta-squared. Significant Group × Time interactions indicate that the experimental group improved significantly more than the control group. Effect size benchmarks for η^2p: small = .01, medium = .06, large = .14.

Post hoc within-group comparisons were conducted using paired-samples *t*-tests; results and corresponding Hedges' *g* effect sizes are summarised in Table 5. In the EG, statistically significant improvements were observed for all five outcome variables (all $p < .001$). The greatest relative improvement was observed for pull-up performance (Δ% = +77.59%, $t(23) = 8.02$, $p < .001$, $g = 1.18$), which exceeded the threshold for a large effect size. Meaningful improvements were also recorded for MB throw distance (Δ% = +9.68%, $g = 0.81$), CMJ height (Δ% = +13.18%, $g = 0.76$), and 15-m start time (Δ% = −4.21%, $g = 0.63$), all of which exceeded the moderate effect threshold of 0.60. Swimming performance improved by a mean of 3.95% ($g = 0.45$), representing a small-to-moderate effect. In the CG, no statistically significant within-group change was detected for any variable (all $p > .05$), and all effect sizes were trivial ($g < 0.10$), confirming that regular swim training alone produced no meaningful performance change over the 8-week period.

Table 5

Within-Group Pre-to-Post Changes, Paired t-Test Results, and Effect Sizes

Variable	**EG (n = 24)**				**CG (n = 24)**			
	Δ%	***t(23)***	***p***	***g***	**Δ%**	***t(23)***	***p***	***g***
50-m freestyle (s)	−3.95	6.84	<.001	0.45	−0.71	1.24	.226	0.08
CMJ (cm)	+13.18	7.41	<.001	0.76	+0.99	0.87	.394	0.06
Pull-up (reps)	+77.59	8.02	<.001	1.18	+4.91	0.62	.540	0.08
MB throw (cm)	+9.68	6.23	<.001	0.81	+0.43	0.51	.615	0.03
15-m start (s)	−4.21	5.17	<.001	0.63	−0.38	0.44	.664	0.06

Note. Δ% = percentage change from pre- to post-training. Negative values for 50-m freestyle and 15-m start indicate faster times (improvement). EG = experimental group; CG = control group; CMJ = countermovement jump; MB throw = medicine ball chest throw. g = Hedges' g. Effect size thresholds: small = 0.20, moderate = 0.60, large = 1.20, very large = 2.00.

To explore potential mechanisms underlying the improvements in swimming performance, Pearson product-moment correlations were computed within the EG between relative changes (Δ%) in 50-m freestyle time and relative changes in each secondary outcome variable. Results are presented in Table 6. Changes in 15-m start time demonstrated the strongest association with changes in 50-m time ($r = .67$, 95% CI [.41, .83], $p < .001$), indicating that reductions in start time were closely linked to overall race time improvement. A significant negative correlation was also found between changes in CMJ height and changes in 50-m time

($r = -.61$, 95% CI [−.80, −.33], $p = .001$), suggesting that gains in lower-limb explosive power contributed to swimming performance improvements, likely through enhanced starts and turns. Improvements in pull-up performance were significantly correlated with improvements in 50-m time ($r = -.58$, 95% CI [−.78, −.29], $p = .003$), consistent with the established role of latissimus dorsi strength in propulsive force generation during the swimming stroke. Changes in MB throw distance showed a moderate, statistically significant negative relationship with changes in 50-m time ($r = -.44$, 95% CI [−.69, −.11], $p = .032$). Collectively, these findings indicate that the dry-land performance adaptations elicited by the intervention were meaningfully associated with concurrent gains in competitive swimming performance, particularly through improvements in lower-limb explosive strength and upper-body pulling capacity.

Table 6

Pearson Correlations Between Relative Changes in 50-m Freestyle Time and Secondary Outcome Variables (Experimental Group, n = 24)

Variable	*r*	95% CI	*p*	Interpretation
ΔCMJ (%)	−.61	[−.80, −.33]	.001	Moderate–large
ΔPull-up (%)	−.58	[−.78, −.29]	.003	Moderate–large
ΔMB throw (%)	−.44	[−.69, −.11]	.032	Moderate
Δ15-m start (%)	.67	[.41, .83]	<.001	Large

Note. Δ = relative change (%) from pre- to post-training. Negative correlations indicate that greater improvement in the predictor was associated with faster 50-m freestyle times. The positive correlation for Δ15-m start reflects that reductions in start time co-occurred with reductions in overall race time. CMJ = countermovement jump; MB throw = medicine ball chest throw. 95% CI = 95% confidence interval for r. Magnitude benchmarks: small = .10–.29, moderate = .30–.49, large = .50–1.00 (Cohen, 1988).

DISCUSSION

The primary aim of this study was to examine the effects of an 8-week in-season low-volume, high-velocity dry-land strength and plyometric training program on sprint swimming performance and associated physical fitness parameters in licensed competitive swimmers aged 13 to 18 years. The results showed significant improvements across all outcome variables in the experimental group (EG), including 50-m freestyle time, countermovement jump (CMJ) height, pull-up repetitions, medicine ball chest throw distance, and 15-m start time.

The EG achieved a mean improvement of 3.95% in 50-m freestyle time following the 8-week intervention, a magnitude that is both statistically significant and practically meaningful. This finding aligns closely with previous investigations of similar design. Marques et al. (2020) reported a 3.9% improvement in 50-m freestyle performance in elite junior swimmers following a 20-week in-season strength training program characterized by low loads, low volume, and maximal execution velocity. The authors attributed these gains to enhanced neuromuscular recruitment and increased rate of force development — adaptations that are especially relevant for sprint events in which performance is determined primarily by the ability to apply maximal propulsive force in the shortest possible time. Similarly, Elrakhawy (2023) demonstrated that a 6-week speed-strength training protocol (30–60% of 1RM) produced a 3.40% improvement in 50-m freestyle performance, a result that surpassed the gains observed in the strength-speed group (2.28%), suggesting that higher-velocity training stimuli may offer greater transfer to sprint swimming performance than heavier-load, lower-velocity approaches. The present study's improvement falls within the range of 1–7% reported across previous dry-land resistance training investigations reviewed by Crowley et al. (2017), who concluded that low-volume, high-velocity resistance-training programmes consistently demonstrated the most favorable transfer to swimming performance.

The absence of any significant within-group improvement in the CG (Δ% = −0.71%, p = .226) further reinforces that the observed gains in the EG were attributable to the training intervention rather than maturational processes, familiarization effects, or seasonal variation. This is an important methodological contribution, as many previous studies in this area have lacked a true control group (Crowley et al., 2017; Guo et al., 2022), limiting the extent to which causal inference could be drawn. The inclusion of a concurrent control group receiving identical swim training without supplementary dry-land work addresses one of the most frequently cited limitations in the swimming strength training literature.

A theoretically and practically relevant feature of the present intervention is its adherence to a low-volume, low-to-moderate load, high-velocity training model. The program prescribed 2 sessions per week using relative loads of 40–65% of 1RM with maximal concentric execution velocity, consistent with the velocity-based training principles advocated by Marques et al. (2020) and supported by the systematic review of Crowley et al. (2017). This approach deliberately avoids the high neuromuscular fatigue associated with heavy-load, high-volume training configurations (i.e., >70% 1RM with repetitions to failure), which have been shown to impair technical quality and increase residual fatigue across subsequent swim sessions (Crowley et al., 2017). From a periodization standpoint, this is particularly relevant during a competitive season, when preserving swimming training quality is paramount. The intervention's design philosophy is also consistent with the "quality versus quantity" debate in swimming coaching, in which expert practitioners have increasingly advocated for training programmes that prioritize intensity and specificity over raw volume, particularly for athletes in the Training to Compete and Training to Win developmental stages (Nugent et al., 2017b). As Nugent et al. (2017b) found through qualitative investigation of elite swimming coaches, quality-focused programs are widely perceived to produce more targeted neuromuscular adaptations for senior and advanced junior swimmers, while aerobic base development through higher volumes remains more appropriate for younger, developing athletes. The present sample's age range (13–18 years) spans both developmental categories, suggesting that the low-volume, high-velocity approach adopted here represents a pragmatic compromise that may stimulate meaningful adaptation without compromising the aerobic development needs of younger participants.

CMJ height improved by 13.18% in the EG following the intervention, reflecting a moderate-to-large effect size (g = 0.76). This result is consistent with Marques et al. (2020), who reported a 12.1% increase in CMJ in elite junior swimmers following a 20-week low-load, high-velocity program. The importance of lower-limb explosive power in sprint swimming is well established: CMJ performance has been shown to correlate significantly with swim start performance, with improvements in vertical jump height associated with faster times to 5 m, 10 m, and 15 m (West et al., 2011; Marques et al., 2020). Elrakhawy (2023) also demonstrated that the speed-strength training group achieved a 5.06% improvement in vertical jump compared to 3.72% in the strength-speed group, further supporting the superior efficacy of higher-velocity, lower-load training for developing explosive power in swimmers.

From a mechanistic standpoint, the improvements in CMJ are likely attributable to neuromuscular adaptations, including enhanced motor unit recruitment, improved rate of force development, and optimized inter- and intra-muscular coordination (Crowley et al., 2017). These adaptations are particularly pronounced when training is performed at maximal intended velocity, as the concentric phase of each repetition is executed with maximal neural activation regardless of the external load. This principle underpins velocity-based training approaches and has been shown to elicit gains in explosive performance that are comparable or superior to those achieved with heavier loads and higher volumes (Marques et al., 2020). The transfer of these lower-limb gains to competitive performance was further supported by the significant negative correlation observed between changes in CMJ height and changes in 50-m freestyle time (r =

−.61, $p = .001$), suggesting that swimmers who improved most in vertical jump also recorded the greatest improvements in race time. This is consistent with the broader evidence that lower-limb power contributes meaningfully to start performance, which in turn is a determinant of 50-m sprint outcomes (Keating et al., 2025; West et al., 2011).

The EG demonstrated a 77.59% improvement in pull-up repetitions ($g = 1.18$), representing the largest relative change and the only outcome to reach the threshold for a large effect size (Hopkins et al., 2009). The magnitude of this improvement likely reflects both a genuine increase in relative upper-body pulling strength and an element of baseline-dependent ceiling effect, given that participants with lower initial pull-up capacities — common in adolescent populations, particularly females — have a greater mathematical potential for percentage improvement. Nonetheless, the absolute gain of approximately 4.5 repetitions per participant in the EG is practically meaningful. Pull-up and lat pull-down performance has consistently been linked to swimming performance in the literature (Perez-Olea et al., 2018). Marques et al. (2020) found that relative changes in pull-up performance were significantly correlated with changes in 50-m freestyle time in female swimmers ($r = -0.99$), and Crowley et al. (2017) identified the latissimus dorsi as the primary muscle involved in the propulsive phase of front crawl swimming, consistent with electromyographic evidence on the competitive swimming strokes (Martens et al., 2015), underscoring the functional relevance of this measure.

Medicine ball chest throw distance improved by 9.68% in the EG ($g = 0.81$), consistent with previous findings linking upper-body explosive power to sprint swimming performance. Elrakhawy (2023) reported an 18.98% improvement in medicine ball chest throw in the strength-speed group, which the author attributed to the high-load, low-velocity protocol's capacity to develop maximal force production. The present intervention's lower absolute magnitude of improvement may reflect the trade-off between load specificity and velocity specificity: while heavy loading maximizes peak force, training at moderate loads with maximal velocity may more selectively develop the rate of force development and explosive power output that is most relevant to swimming strokes (Crowley et al., 2017; Guo et al., 2022). The significant negative correlation between changes in MB throw distance and changes in 50-m time ($r = -.44$, $p = .032$) provides further evidence that upper-body explosive power improvements are mechanistically linked to sprint swimming performance.

A 4.21% improvement in 15-m start time was observed in the EG following the intervention ($g = 0.63$), and this variable showed the strongest correlation with changes in 50-m freestyle time ($r = .67$, $p < .001$). This finding reinforces the established understanding that the swim start — encompassing block, flight, and underwater phases — is a critical determinant of sprint swimming performance (Keating et al., 2025; West et al., 2011). The start phase makes a disproportionate contribution to 50-m race time relative to its distance, given the high horizontal velocities achieved during the block and flight phases and the momentum sustained through the underwater glide. Improvements in both vertical jump height and lower-body strength, as observed in the present study, are consistent with the biomechanical demands of the swim start, which requires powerful extension of the ankle, knee, and hip joints (Marques et al., 2020). Keating et al. (2025) demonstrated in an elite 50-m freestyle specialist that a 3.5% improvement in free swimming time (15–45 m) contributed substantially to a 1.3% improvement in official race time following a 6-week individualized in-water resistance training intervention informed by load-velocity profiling. While the present study did not segment race performance, the magnitude of improvement in 50-m time (3.95%) aligns well with this evidence and suggests that the gains in start and propulsive capabilities may underlie the observed improvements in overall race time.

The systematic review by Guo et al. (2022) examining resistance training methods and intensity in adolescent swimmers concluded that a low-intensity, high-speed resistance training programme is most appropriate for this population to achieve optimal training outcomes. The authors identified 16 studies meeting their inclusion criteria and found that both in-water and dry-land resistance training improved swimming performance at distances of 50 m, 100 m, 200 m, and 400 m, with the majority of evidence concentrated on 50 m and 100 m events. The present study's intervention design aligns directly with this recommendation, employing loads of 40–65% 1RM with maximal concentric velocity, a configuration that prioritizes neuromuscular efficiency over morphological hypertrophy. This is especially important for adolescent athletes, for whom the risk of overtraining injury and the potential negative effects of excessive resistance on developing musculoskeletal structures must be carefully managed (Guo et al., 2022). Furthermore, Crowley et al. (2017) noted that high-volume resistance training programmes tend to produce hypertrophic rather than neuromuscular adaptations, which may actually impair swimming performance by increasing body drag without proportionally increasing propulsive capacity. The present study's low-volume design circumvents this risk while still eliciting meaningful performance adaptations.

In addition to the intensity parameters, the bilateral nature of the training program — incorporating both upper (bench press, pull-ups, shoulder press) and lower limb exercises (full squat, squat jump, CMJ) — likely contributed to the breadth of performance improvements observed. Crowley et al. (2017) identified the exclusive focus on upper-limb exercises as a methodological limitation of several earlier studies, noting that lower-limb strength is a key determinant of start performance and overall sprint capability. Guo et al. (2022) similarly highlighted that the majority of reviewed studies focused on either in-water or dry-land training in isolation, with none examining the combined effect of both modalities. The present study's comprehensive dry-land approach, targeting both upper and lower body musculature, may therefore offer a more complete stimulus for performance enhancement than single-modality interventions.

While the present study focused exclusively on dry-land training, emerging evidence suggests that in-water resistance training may offer additional specificity advantages that complement gym-based programs. Keating et al. (2025) applied load-velocity profiling to guide individualized in-water resistance training in an Olympic-level 50-m freestyle specialist and observed likely improvements in maximal swim velocity (+3.4%), theoretical maximal load (+13.6%), and a 1.3% improvement in official race time. The authors argued that the superior transfer of in-water resistance training — relative to dry-land training — stems from its biomechanical specificity, allowing swimmers to develop propulsive force under conditions that closely replicate competitive racing kinematics. This principle is consistent with the dynamic correspondence theory cited by Crowley et al. (2017), which states that resistance training exercises must share similar joint angular ranges, velocity characteristics, and muscle activation patterns with the target sport skill to maximize transfer. Future research in adolescent populations should examine whether a combined dry-land and in-water resistance program, as recommended by Guo et al. (2022), produces additive or synergistic effects on sprint swimming performance beyond those achievable through either modality alone.

Swimming velocity is the mathematical product of stroke length and stroke rate (Craig & Pendergast, 1979), and both technical parameters have been linked to improvements in sprint swimming performance following resistance training interventions. Elrakhawy (2023) reported significant improvements in stroke length following both strength-speed and speed-strength training protocols, while stroke rate was significantly improved only in the strength-speed group. The author interpreted these findings in the context of the inverse relationship between stroke length and stroke rate: as swimmers increase propulsive force per stroke — a likely consequence of strength training — stroke length tends to increase while stroke rate may decrease or stabilize. Crowley et al. (2017) corroborated this pattern in their systematic review, noting that low-repetition, high-intensity resistance training was most effective for increasing stroke length, while resisted swims presented a more viable modality for increasing stroke rate.

Although the present study did not assess stroke biomechanics directly, the significant improvements in swimming time, upper-body strength, and explosive power observed in the EG are consistent with the mechanisms through which resistance training is proposed to enhance stroke efficiency and propulsive force application (Crowley et al., 2017; Guo et al., 2022).

Limitations

Several limitations of the present study warrant consideration. The 8-week intervention period, while consistent with the short-to-medium duration interventions most commonly reported in the swimming strength training literature (Crowley et al., 2017), may not be sufficient to capture the full range of physiological adaptations associated with longer-term programs. Marques et al. (2020) noted that their 20-week program allowed for progressive overload across two training cycles, which may have contributed to the sustained and cumulative nature of their observed gains. Future studies should examine whether the present intervention's effects are maintained, amplified, or attenuated over longer competitive seasons. Additionally, the absence of stroke biomechanical analysis in the present study precludes a mechanistic examination of how the observed physical improvements translated to changes in stroke length, stroke rate, and propulsive efficiency — parameters that are central to a complete understanding of how dry-land strength training influences swimming performance (Crowley et al., 2017; Elrakhawy, 2023). Future research should incorporate video-based or tethered swimming analysis to characterize these technical adaptations. Furthermore, while the present study controlled for dry-land training volume, it did not account for individual variability in in-water training content, which may have introduced confounding variation in training load. Larger, multi-site studies with more rigorous control of all training variables and the inclusion of objective workload monitoring (e.g., session RPE, GPS-based volume tracking) would strengthen the evidence base. Finally, the generalizability of the present findings to female-only or male-only samples, and to swimmers specializing in strokes other than freestyle, remains to be determined, as the present sample was mixed in sex and stroke specialty. In addition, biological maturation was not formally assessed, so maturity-related influences on the observed adaptations cannot be ruled out; future studies should include a maturity indicator (e.g., maturity offset or Tanner staging). Finally, the 50-m freestyle and 15-m start outcomes were obtained with manual and photocell timing rather than official electronic timing, and although two timekeepers were averaged for the 50-m trials, the precision of manual timing is lower than that of fully automatic systems and may not capture very small performance changes; this should be considered when interpreting the magnitude of the swimming results.

Practical Implications

The results of the present study offer several actionable recommendations for swimming coaches and strength and conditioning practitioners working with adolescent competitive swimmers. First, two weekly sessions of dry-land strength training incorporating both upper and lower body exercises at 40–65% of 1RM with maximal concentric execution velocity can be effectively integrated into a competitive season without compromising swim training quality or inducing excessive neuromuscular fatigue. Second, bilateral program design targeting the full kinetic chain — including squats, squat jumps, CMJ, bench press, pull-ups, and shoulder press — appears to elicit the most comprehensive physical adaptations, addressing both propulsive force generation and explosive start capabilities. Third, given the significant correlations between changes in CMJ, pull-up performance, and 50-m freestyle time, these dry-land assessments can serve as practical surrogate markers for monitoring transfer of training to competitive swimming performance during the season. These recommendations are consistent with the guidelines emerging from systematic reviews (Crowley et al., 2017; Guo et al., 2022) and empirical investigations (Marques et al., 2020; Elrakhawy, 2023) and are feasible for implementation in club and national training center environments.

Conclusion

The findings of this study indicate that an 8-week in-season low-volume, high-velocity dry-land strength and plyometric training program, performed twice weekly alongside regular competitive swim training, was associated with significant and practically meaningful improvements in 50-m freestyle performance, lower-limb explosive power, upper-body pulling strength, explosive propulsive capacity, and swim start time in adolescent competitive swimmers aged 13 to 18 years. The absence of any meaningful change in the control group suggests that these adaptations were most plausibly attributable to the supplementary training intervention rather than to swim training alone, seasonal variation, or maturation. Significant correlations between changes in dry-land performance and changes in race time — particularly for 15-m start time ($r = .67$), CMJ height ($r = -.61$), and pull-up performance ($r = -.58$) — suggest that the observed swimming improvements may be related to neuromuscular adaptations in lower-limb explosive power and upper-body pulling capacity, although these mechanisms were not directly measured and should be interpreted as plausible rather than established. These results are consistent with those of Marques et al. (2020) and the conclusions of systematic reviews identifying low-volume, high-velocity resistance training as a favourable modality for transfer to competitive swimming performance. Coaches and strength and conditioning professionals working with adolescent swimmers should therefore consider integrating this type of in-season dry-land program into their athletes' competitive preparation as a feasible and evidence-based strategy for enhancing sprint swimming performance. Future research should examine the effects of combined dry-land and in-water resistance training over longer intervention periods and incorporate stroke biomechanical analysis to further elucidate the mechanisms through which physical adaptations transfer to in-water performance.

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Author(s)' statements on ethics and conflict of interest

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