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Original Article

Effects of a combined land–water coordination training program on sprint performance in youth swimmers

HAMID VALIJONOV[1], LAZIZ KHOLMURODOV[2], DJAMSHID UMAROV[3], SAMANDAR HABIBULLAYEV[4], DURYOD EGAMOV[5], SHAKHNOZA IRGASHEVA[6], KHUSANBOY ARABOV[7], KHURSHID KURBONOV[8], ABDULAZIZ HAMIDJONOV[9]
[1,5,9]Institute of Scientific Research of Physical Education and Sport, Tashkent, UZBEKISTAN
[2,3,6,7,8]Uzbek State University of Physical Culture and Sport, Chirchik, UZBEKISTAN
[4] Chirchik State Pedagogical University, Chirchik, UZBEKISTAN

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Abstract:
Background: Stroke coordination is a key factor in sprint performance among youth front-crawl swimmers. Although coaches commonly use both land and in-water coordination drills, the effects of a combined land–water coordination program on stroke timing are not yet clear. Because young athletes have limited training time and need adequate recovery, interventions that improve performance without increasing weekly training volume are especially valuable. **Purpose:** This study evaluated the effects of a 12-week combined land–water coordination program on sprint performance and stroke coordination in young swimmers. We hypothesized that the combined-training group would achieve greater improvements in 50 m freestyle time than standard training. **Methods**: In a parallel-group randomized controlled trial, 52 male sports school swimmers (12.0 ± 0.6 years) were assigned to either the experimental group (n = 26) or the control group (n = 26). The experimental group completed three combined sessions per week (30 minutes on land and 30 minutes in water per session) for 12 weeks, while the control group continued standard training with matched weekly volume and frequency. Sprint performance was measured using two 50 m trials; the faster time was used unless the two times differed by more than 0.10 seconds, in which case the mean was used. Stroke coordination (Index of Coordination, IdC), stroke rate (SR), and stroke length (SL) were calculated from synchronized above- and underwater videos (120 fps) digitized in Kinovea (v0.9.5). **Results:** Sprint time improved by −0.32 ± 0.24 s in the experimental group compared to −0.11 ± 0.14 s in the control group (Time × Group: $F(1, 50) = 14.63$, $p < .001$, $\eta p^2 = 0.226$; Hedges' $g = 1.05$). IdC remained negative in both groups and became slightly more negative in the experimental group, indicating a slightly longer gap between arm strokes (−0.45 percentage points vs −0.03 percentage points; $p = .023$). Stroke rate increased more in the experimental group (+1.40 vs +0.17 cycles·min^{-1}; $p < .001$), while stroke length showed no significant interaction ($p = .060$). **Conclusion:** The program led to small but potentially decisive improvements in 50 m performance (experimental: −0.32 ± 0.24 s, approximately 0.8%; net benefit vs control: −0.21 s, approximately 0.6%), without an increase in total training volume. These improvements resulted mainly from a higher stroke rate, while stroke length showed minimal change and IdC remained within the catch-up range.
Key Words: front crawl, stroke coordination, Index of Coordination (IdC), stroke rate, stroke length

Introduction

The Index of Coordination (IdC) is an effective metric for measuring stroke-timing efficiency in front crawl swimming. As velocity and proficiency increase, IdC values shift from negative (catch-up mode) to positive (superposition mode) (Chollet et al., 2000). These results align with Seifert et al. (2010), who found that higher swimming speed and skill level lead to more synchronized limb coordination and IdC values moving toward superposition (closer to 0%). Teaching effective motor skills in swimming is especially important during childhood (ages 5–12), when foundational movement patterns and coordination develop (Minkels et al., 2025).
Elite front crawl swimmers reduce glide pauses as their speed surpasses approximately 1.7 m/s, transitioning from catch-up coordination (IdC < 0%) to superposition (IdC > 0%), which directly links coordination to sprint performance (Carmigniani et al., 2020).

Recent cluster analyses show that, among swimmers aged 11–13, sprint velocity depends mainly on anthropometric factors and stroke efficiency measures, such as stroke index and stroke length, rather than on coordination mode alone (Figueiredo et al., 2016). At this stage of development, front crawl coordination typically demonstrates catch-up arm timing (IdC ≈ −6% to −7%). This pattern indicates a stronger relationship between velocity and stroke length, rather than dependence on stroke rate (Silva et al., 2012). While many studies have examined coordination training in isolation, empirical evidence on combined land–water coordination training remains limited. Related rhythm-based programs in swimmers report benefits for

Corresponding Author: HAMID VALIJONOV, E-mail: hamid.valijonov@gmail.com

coordination and short-sprint performance. These land-focused protocols do not specify how to integrate land and water stimuli within a single mesocycle, so coaches lack clear guidance (Yin et al., 2023). In this study, "combined land–water coordination training" refers to the integrated program of land-based and in-water coordination exercises.

Coordination is discipline-specific and develops through targeted practice and experience. For example, orienteers demonstrate better dynamic balance and coordination than distance runners (Machowska-Krupa & Cych, 2023). Elite butterfly swimmers reduce the gap between their arm and leg movements as their pace increases, while novices experience longer delays (Seifert et al., 2008). Studies of young athletes indicate that exposure to multiple sports leads to better motor coordination than specializing in one sport, highlighting the developmental benefits of diverse movement experiences (Stanković, Horvatin et al., 2023).

From an ecological-dynamics perspective, coordination variability is a beneficial adaptation to task, environmental, and individual constraints, supporting more flexible motor strategies (Seifert et al., 2014). Manipulating task constraints, such as varying swimming speeds and stroke frequencies, can promote adaptive coordination patterns in young swimmers (Silva, Figueiredo, Morais et al., 2019). Short-term, coordination-focused interventions have improved sport-specific metrics, such as countermovement jump height and agility, in adolescent athletes (González-Fernández et al., 2021), and have also enhanced cognitive functions, including visuospatial attention and working memory (Latino et al., 2021; Müller et al., 2025). Recent research shows that coordination-based movement education significantly improves fundamental motor skills and attention in preschool children, highlighting the broad cognitive and motor benefits of structured coordination training interventions (Kurnaz & Altinkök, 2023).

In swimming, the combined effect of repetitive muscular strength and coordination explains over 60% of the variance in sprint performance (Nikšić et al., 2019). Increased muscle strength, power, lean body mass, flexibility, and both aerobic and anaerobic capacity significantly predict success in youth swimming (Đurović et al., 2017; Price et al., 2024). Coaches widely use land-based strength and neuromotor drills to improve sprint performance in age-group swimmers. Recent trials show that plyometric blocks increase 30 m dash speed and agility in novice male swimmers (Soni & Vedawala, 2022), and that quickness-ladder and cone routines reduce 50 m freestyle time in competitive swimmers aged 14 to 16 years (Gul & Aydogan, 2021). Structured speed, agility, and quickness (SAQ) training programs also improve stroke mechanics and sprint speed in adolescent swimmers, demonstrating that land-based agility and quickness exercises transfer to in-water sprint performance (Pradittakarn et al., 2025). In addition, regular swimming practice improves postural stability and neuromuscular activation in children, indicating broader neuromuscular benefits beyond immediate performance outcomes (Baccouch et al., 2024).

Despite extensive research on motor coordination and swimming performance, limited evidence directly examines the effects of combined land–water coordination training interventions on stroke timing in young swimmers. Recognizing the importance and adaptability of coordination, this randomized controlled trial evaluated the effects of a novel combined land–water coordination training program on integrated coordination (IdC) and sprint performance in young front crawl swimmers. This study tested whether a 12-week program that combined land-based rhythm and balance exercises with in-water coordination drills would improve (i) 50 m sprint performance and (ii) stroke synchronization metrics (IdC, stroke rate, and stroke length) more than standard training in swimmers aged 11–13 years. We hypothesized that the combined program would improve 50 m sprint performance compared to standard training, primarily through better stroke-rate control, with small or uncertain changes expected in timing metrics (IdC and stroke length).

Materials and Methods

A total of 52 male youth swimmers participated in this parallel-group randomized controlled trial, with 26 in the experimental group and 26 in the control group (mean age: 12.0 ± 0.6 years; age range: 11–13 years). The study took place at the Specialized Children's and Youth Sports School for Water Sports in Tashkent, Uzbekistan. Inclusion criteria were: (1) at least one year of structured swimming training with a minimum of three sessions per week, (2) no injuries in the previous six months, and (3) no participation in other organized sports during the study period. Randomization used a computer-generated list, with allocation concealment ensured by sequentially numbered, opaque, sealed envelopes prepared by an independent assistant. Baseline characteristics (age, body mass, height, 50 m sprint time, IdC, stroke rate, and stroke length) did not differ significantly between the two groups (all $p > .05$; see Table II). An a priori power analysis was conducted using G*Power 3 (Faul et al., 2007) for a two-way mixed ANOVA (2 groups × 2 time points), with the Time × Group interaction as the primary effect of interest. Assuming a medium effect size ($f = 0.25$), $\alpha = 0.05$, power = 0.80, pre–post correlation $r = 0.50$, and nonsphericity correction $\varepsilon = 1.0$, the estimated total sample size required was 52 swimmers. This result informed our recruitment goal of 26 participants per group.

Both parents or guardians and the underage swimmers provided written consent to participate in this study. All procedures followed the Declaration of Helsinki for human research. The Board of the Institute of Scientific Research of Physical Education and Sport also approved the research design.

Training intervention

A 12-week intervention period was chosen because reviews indicate that shorter programs often do not improve balance-related outcomes, likely due to insufficient duration; a 12-week period may reduce this risk (Zaragas et al., 2023), as previous studies have shown that this length improves coordination in young swimmers (Latino et al., 2021). Participants trained three times per week under the supervision of certified coaches. The experimental group replaced standard technical sets with a structured combined coordination program, also conducted three times per week. Both groups had the same weekly training volume and frequency; only the training content differed. The coordination intervention used a three-phase progression adapted from Silva et al. (2022), combining land and in-water drills (3 sessions per week, each with 30 minutes on land and 30 minutes in water). Intensity during the drills was guided by the rating of perceived exertion (RPE; 0–10 scale). The structured progression is summarized in Table I.

Table I. Phased progression of the combined land–water coordination training (3 sessions·week^{-1}; each session 30 min land + 30 min water; total ≈60 min).

Phase	Weeks	Primary focus	Land drills (30 min)	In-water drills (30 min)	Cueing & progression
1	1-4	Basic neuromotor control	Agility ladder; single-leg wobble-board balance; partner ball throws; Simple reaction footwork. Dose: 4–5 drills × 2–3 × 30–45 s; Rest 30 s; RPE 3–4.	One-arm front crawl (alternate); catch-up freestyle; tempo-based kicking with arm pause; sculling. Dose: 2–3 × 25 m per drill; rest 20–30 s; easy–moderate.	Tempo Trainer Pro (Mode 3); SR ≈48 cycles·min^{-1} (1 cycle = both arms).
2	5-8	Rhythmic & Reactive coordinatio n	Add perturbations; varied targets; faster cadence. Dose: 3–4 × 30–45 s; rest 30 s; RPE 4–5.	Reduce catch-up gap; Link breathing timing; Quicker partner synchrony; 25–50 m reps. Dose: 3–4 reps; rest 20 30 s.	Increase SR by ≈1 cycle·min^{-1} every 2–3 weeks (≈49–50).
3	9-12	Integration under time pressure	Error-free execution under time constraints. Dose: 3–4 × 30–45 s; rest 20–30 s; RPE 5–6.	Near-continuous propulsion at higher SR; race-pace synchrony; whole-stroke timing focus; 25–50 m. Dose: 4 reps; rest 15–20 s.	Target SR ≈50–51 cycles·min^{-1} while maintaining technique.

Note: SR = stroke rate (cycles·min^{-1}). RPE = rating of perceived exertion (0–10). Tempo cueing used Mode 3; mid-pool segments only were analyzed. Warm-up/cool-down as in Assessment procedures.

Swimmers wore the Tempo Trainer Pro (FINIS, United States) under their caps during the in-water coordination sets (see Figure 1). Audio cues were delivered mainly in Mode 3 (stroke cycles·min^{-1}) and occasionally in Mode 1 (fixed intervals). Stroke-rate targets were individualized based on baseline values (approximately 48 cycles·min^{-1}, with 1 cycle defined as both arms) and increased by about 1 cycle·min^{-1} every 2–3 weeks, reaching approximately 50–51 cycles·min^{-1} over 12 weeks. Analyses included only mid-pool segments.

Fig. 1. Placement of the Tempo Trainer Pro for underwater stroke-rate cueing. The Tempo Trainer Pro is placed just behind the swimmer's ear and secured under the cap or to the goggle strap to maintain audibility while keeping a low profile. The photograph is reproduced with parent or guardian and participant consent, and faces are de-identified.

Coaches gave verbal feedback during all sessions. No inertial sensors were used; the only wearable device was an audible pacing metronome (the Tempo Trainer Pro). The control group performed standard endurance and technique drills without an explicit focus on coordination. Their training frequency and volume matched those of the experimental group. The control group continued their usual swimming sessions, which included endurance sets (e.g., 4 × 200 m freestyle at moderate intensity), technique drills (e.g., sculling, freestyle drills with fins), and coach-guided feedback. No specific land-based neuromotor training or in-water stroke coordination drills were included.

Assessment procedures

Participants completed pre- and post-intervention testing one week before and after the 12-week training program. Testing took place at the same time of day in a controlled indoor environment. Each session began with a standardized warm-up routine: 10 minutes of light aerobic swimming, dynamic stretching, and one brief 15 m build-up sprint to ensure readiness without causing fatigue. All 52 participants completed the study, and no injuries or adverse events occurred. Attendance in the experimental group averaged 92% (range: 85–100%).

Body mass and standing height were measured using a combined digital scale and stadiometer (Meubon Body Fat/Height Scale; Meubon Medical Supplies, Houston, TX, USA). All measurements were taken with swimmers barefoot and in swimwear, before training, by the same assessor. The device was zeroed before each session. Body mass was recorded to the nearest 0.1 kg, and height to the nearest 0.1 cm. Two readings were obtained and averaged; a third reading was taken if values differed by more than 0.2 kg or 0.5 cm. Body mass index (BMI) was calculated as $kg \cdot m^{-2}$. No bioimpedance or body fat estimates from the device were used in the analyses.

Swimmers completed two 50-m front-crawl sprints at maximal effort from a push start in a 25-m pool maintained at 27–28 °C (80.6–82.4 °F), following World Aquatics guidelines. Two independent researchers recorded times using handheld stopwatches (Technos YP2151/8P, Brazil; 0.01-s resolution). If the two times differed by 0.10 s or less, the faster time was used; if the difference was greater than 0.10 s, the mean of the two times was used. No pacing devices (including the Tempo Trainer Pro) were used during testing. Timekeepers were not blinded to group allocation. To reduce potential bias, a standardized timing protocol was followed.

Swimming trials were recorded using two GoPro HERO12 Black cameras positioned to minimize parallax error. The underwater camera (2.7K, 120 fps) was mounted on a weighted tripod 1.0 m below the surface, 12.5 m from the end of the pool, and perpendicular to the swimming path. The above-water camera (4K, 120 fps) was mounted 1.5 m above deck level and angled downward at approximately 15° to capture sagittal-plane stroke mechanics. HyperSmooth 6.0 stabilization was enabled. Video footage, excluding starts and turns, was digitized frame by frame in Kinovea (version 0.9.5; Kinovea Team, 2021) across six to eight consecutive stroke cycles. A 1 m underwater scale was used for spatial calibration, and the 2D calibration and digitization workflow followed validated procedures (Silva et al., 2012).

The IdC was calculated using the four-phase arm-stroke model (Chollet et al., 2000), which measures the temporal relationship between the propulsive phases of both arms. Negative IdC values indicate catch-up timing, meaning reduced overlap, while values near 0% reflect greater continuity of propulsion, or superposition. Stroke rate (SR; $cycles \cdot min^{-1}$) and stroke length (SL; $m \cdot cycle^{-1}$) were also obtained from the same digitization footage. Stroke rate was determined by counting the number of complete arm cycles per unit of time, and stroke length was calculated by dividing the distance swum by the number of stroke cycles. All analyses used mid-pool segments to exclude start and turn phases.

All video analyses were conducted by a single trained researcher who was not blinded to group or time point; this potential source of bias is acknowledged as a limitation. To reduce expectancy effects, the researcher followed a pre-specified scoring protocol, and all processing was completed in batch without access to the sprint-time results.

Statistical analysis

We assessed data normality and homogeneity of variance using the Shapiro–Wilk and Levene's tests (all $p \geq .18$), confirming that the data were suitable for parametric testing. For each outcome (50 m sprint time, IdC, stroke rate, stroke length), we conducted a 2 × 2 mixed ANOVA with Time (pre, post) as the within-subject factor and Group (experimental, control) as the between-subject factor. We report partial ηp^2 as the effect size. When we observed a significant Time × Group interaction, we performed Šidák-adjusted post-hoc pairwise comparisons. Between-group effects for the intervention were calculated as Hedges' g on change scores (post−pre) using the pooled SD with the small-sample correction and 95% confidence intervals. All analyses were performed in JASP (Version 0.19.3; JASP Team, 2025) with $\alpha = 0.05$. We defined the smallest worthwhile change (SWC) for 50 m time as 0.2 × the between-athlete SD at baseline (pooled across groups). In this sample, the pooled baseline SD was approximately 1.42 s, resulting in SWC ≈ 0.28 s.

Results

All variables met the assumptions of normality and homogeneity (Shapiro–Wilk $p \geq .18$). A total of 52 male swimmers (26 experimental, 26 control) completed all testing. Baseline characteristics did not differ significantly between groups, as shown in Table II.

Table II. Baseline characteristics of participants

Characteristic	Control (Mean ± SD)	Experimental (Mean ± SD)	p-value
N	26	26	
Sex	Male 26 (100%)	Male 26 (100%)	1.000
Age (y)	12.01 ± 0.63	12.02 ± 0.58	.949
Body Mass (kg)	45.02 ± 4.14	46.02 ± 3.79	.368
Height (cm)	150.28 ± 4.00	151.34 ± 4.08	.349
BMI (kg·m^{-2})	19.91 ± 1.44	20.08 ± 1.28	.657
Sprint time (s)	38.15 ± 1.32	38.05 ± 1.50	.803
IdC (%)	-8.28 ± 1.37	-8.53 ± 1.46	.525
Stroke Rate (cycles·min^{-1})	47.98 ± 4.43	48.25 ± 4.16	.827
Stroke Length (m·cycle^{-1})	1.65 ± 0.09	1.66 ± 0.09	.575

Note: Values are mean ± SD unless otherwise indicated. p-values for continuous variables are from independent-samples t-tests (Welch's correction). Sex p-value from Fisher's exact (or χ^2 if >2 categories).

Sprint time (primary outcome)

A 2 × 2 mixed ANOVA showed a significant main effect of time, $F(1, 50) = 63.16$, $p < .001$, $\eta p^2 = .558$, and a significant Time × Group interaction, $F(1, 50) = 14.63$, $p < .001$, $\eta p^2 = .226$; the main effect of group was not significant, $F(1, 50) = 0.27$, $p = .603$. Sprint time improved in both groups, with a greater reduction in the experimental group (−0.32 ± 0.24 s) compared to the control group (−0.11 ± 0.14 s), resulting in a between-group difference of −0.21 s; Hedges' g = 1.05, 95% CI [0.47, 1.63]. Within-group tests indicated significant sprint-time reductions in both groups (experimental: −0.32 ± 0.24 s, $p < .001$; control: −0.11 ± 0.14 s, $p < .001$), with the experimental group showing a larger improvement (Figure 2).

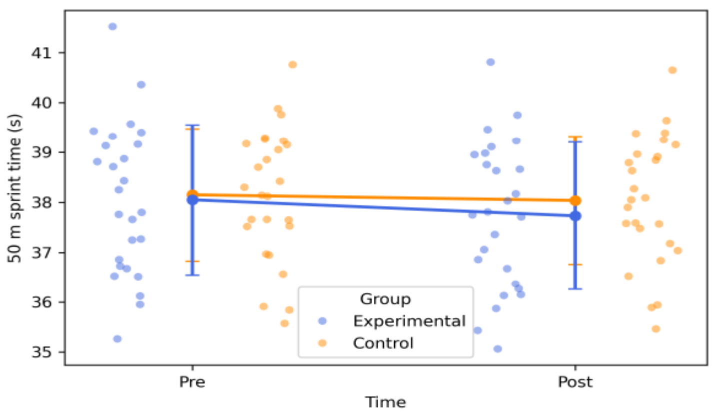

Fig. 2. Change in 50 m sprint time after the 12-week intervention. Each dot represents one swimmer; bars show mean ± SD of the change. The experimental group improved by –0.32 ± 0.24 s; the control group changed by –0.11 ± 0.14 s (negative values indicate faster times). Mixed ANOVA Time × Group: $F(1, 50) = 14.63$, $p < .001$, $\eta p^2 = .226$. Between-group difference in change: –0.21 s; Hedges' *g* = 1.05 (95% CI [0.47, 1.63]).

Table III. Pre–post changes by group and Group × Time interaction (mixed ANOVA, df = 1, 50)

Outcome	Group	Pre (Mean ± SD)	Post (Mean ± SD)	Δ (Post–Pre)	F(1, 50)	p	partial η^2
Sprint (s)	Control	38.150 ± 1.322	38.038 ± 1.281	−0.112	14.63	< .001	.226
	Experimental	38.052 ± 1.503	37.732 ± 1.471	−0.320			
IdC (%)	Control	−8.277 ± 1.371	−8.302 ± 1.291	−0.025	5.48	.023	.099
	Experimental	−8.528 ± 1.458	−8.975 ± 1.305	−0.447			
Stroke Rate (cycles·min^{-1})	Control	47.985 ± 4.431	48.158 ± 4.352	+0.173	133.40	< .001	.727
	Experimental	48.246 ± 4.164	49.650 ± 4.153	+1.404			
Stroke Length (m·cycle^{-1})	Control	1.647 ± 0.092	1.650 ± 0.093	+0.003	3.71	.060	.069
	Experimental	1.661 ± 0.090	1.685 ± 0.101	+0.024			

Note: Values are mean ± SD. Δ = Post − Pre. Negative IdC indicates catch-up coordination. p-values and effect sizes refer to the Group × Time interaction. Pairwise comparisons used Šidák-adjusted 95% CIs. IdC changes are reported in percentage points (pp).

Using SWC = 0.2 × the between-athlete SD of baseline 50 m time (≈ 0.2 × 1.42 s ≈ 0.28 s), the experimental group's mean within-group improvement (−0.32 s) meets the smallest worthwhile change (SWC) threshold, while the control group's change (−0.11 s) does not.

IdC

Both the main effect of time ($F(1, 50) = 6.86$, $p = .012$, $\eta p^2 = .121$) and the Time × Group interaction ($F(1, 50) = 5.48$, $p = .023$, $\eta p^2 = .099$) were significant; however, the group main effect was not significant ($F(1, 50) = 1.60$, $p = .212$). IdC remained negative (catch-up timing) in both groups, with a change of −0.45 percentage points (pp) in the experimental group and −0.03 pp in the control group. Šidák-adjusted post-hoc tests showed that the experimental group's IdC became slightly more negative ($p = .005$), while the control group showed no significant change ($p = .81$) (Figure 3).

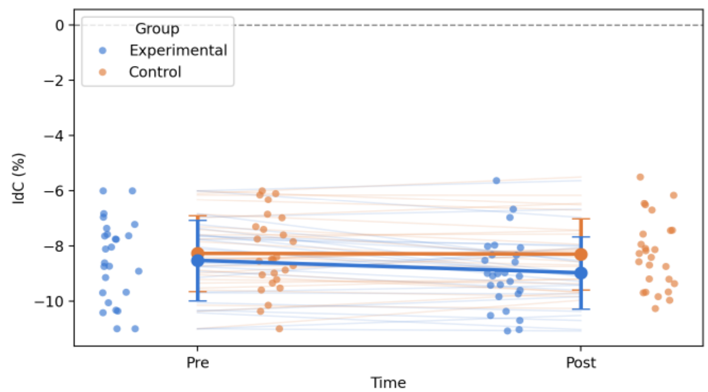

Fig. 3. Individual pre-to-post changes in the Index of Coordination (IdC). Each line represents one swimmer. Negative IdC values reflect catch-up timing; values nearer 0% indicate more continuous propulsion (greater arm-phase overlap). Mean change (mean ± SD): experimental −0.45 ± 0.75 percentage points (pp); control −0.03 ± 0.54 pp. Mixed ANOVA: time, $F(1, 50) = 6.86$, $p = .012$; Time × Group, $F(1, 50) = 5.48$, $p = .023$; group, $F(1, 50) = 1.60$, $p = .212$. Paired comparisons (Šidák-adjusted): experimental $p = .005$; control $p = .81$.

Stroke rate

Stroke rate increased significantly over time, $F(1, 50) = 192.86$, $p < .001$, $\eta p^2 = .794$, with a large Time × Group interaction, $F(1, 50) = 133.40$, $p < .001$, $\eta p^2 = .727$. The experimental group increased by 1.40 cycles·min^{-1}, while the control group increased by 0.17 cycles·min^{-1} (Figure 4).

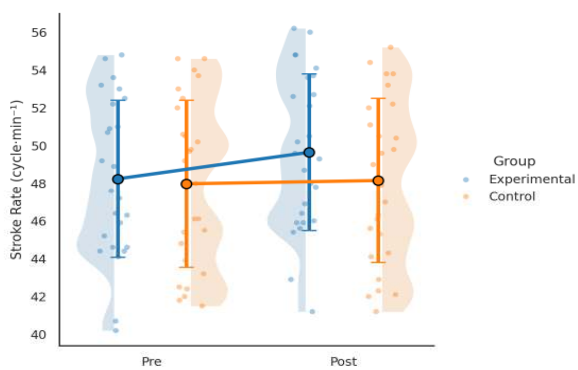

Fig. 4. Stroke rate increased significantly over time, $F(1, 50) = 192.86$, $p < .001$, $\eta p^2 = .794$, with a highly significant Time × Group interaction, $F(1, 50) = 133.40$, $p < .001$, $\eta p^2 = .727$. The experimental group increased stroke rate by +1.40 cycles·min^{-1}, compared with +0.17 cycles·min^{-1} in the control group. This corresponds to an ≈3% increase in SR in the experimental group (from ~48.2 to ~49.7 cycles·min^{-1}) versus ≈0.4% in controls.

Stroke length

There was no significant main effect of time ($p = .060$) and no significant Time × Group interaction, $F(1, 50) = 3.71$, $p = .060$, $\eta p^2 = .069$. Stroke length changed minimally in both groups, with an increase of 0.024 m·cycle^{-1} in the experimental group and 0.003 m·cycle^{-1} in the control group (Figure 5).

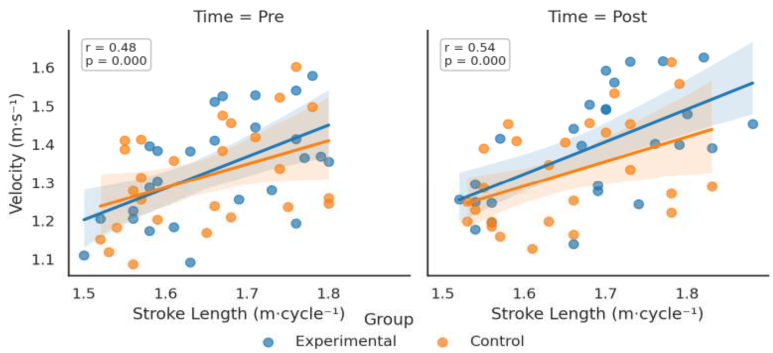

Fig. 5. Stroke length (m·cycle⁻¹) before and after the 12-week intervention in the experimental and control groups. No significant main effect of time ($p = .060$) and no significant Time × Group interaction**,** $F(1, 50) = 3.71$, $p = .060$, $\eta p^2 = .069$. Changes were small in both groups (+0.024 vs +0.003 m·cycle⁻¹). Error bars represent ±SD.

Discussion

This randomized trial showed that the experimental group achieved a greater reduction in 50 m sprint time than the control group (Time × Group: $F(1, 50) = 14.63$, $p < .001$, $\eta p^2 = 0.226$). The speed gain in the experimental group was accompanied by a marked increase in stroke rate (+1.40 vs +0.17 cycles·min⁻¹; $F(1, 50) = 133.40$, $p < .001$, $\eta p^2 = 0.727$), while stroke length showed only a small, non-significant difference between groups ($F(1, 50) = 3.71$, $p = .060$, $\eta p^2 = 0.069$). As expected, stroke length did not significantly change, indicating that sprint improvements were primarily due to stroke-rate adaptations. At a baseline of approximately 38 s, the between-group difference of −0.21 s corresponds to about 0.55% over 12 weeks. This is a meaningful gain at this level, achieved without increasing total training volume.

Our findings respond to the need for more sport-specific coordination training research in youth swimming (Budiman et al., 2025). The combined land–water drills produced a small but statistically significant change in stroke coordination (IdC: Δ = –0.45 pp vs –0.03 pp in controls; Time × Group: $F(1, 50) = 5.48$, $p = .023$), indicating a slightly longer inter-arm gap (less overlap and more catch-up). Although IdC became slightly more negative, sprint speed still increased. This shows that stroke timing is trainable and changed along with stroke tempo, while IdC remained within the catch-up range. The slight shift toward greater catch-up may indicate a coordination strategy that allows for a higher stroke rate while maintaining stroke length in this age group. At this developmental stage, small increases in catch-up can occur alongside improved rate control and faster times, which aligns with youth front-crawl studies that highlight the trade-off between stroke rate and stroke length rather than strict overlap timing patterns. Reductions in stroke length with preserved coordination have also been observed during longer efforts, supporting the idea that changes in speed may result from power or fatigue rather than changes in inter-arm timing (Schnitzler et al., 2009). This reflects adaptive coordination responses observed in other sports. For example, orienteers show better dynamic balance than runners (Machowska-Krupa & Cych, 2023), and gymnasts perform better than single-environment athletes in general motor coordination tasks (Jaakkola et al., 2017). In football, agility and jumping performance improved after brief coordination-focused interventions, although sprint performance did not increase directly (González-Fernández et al., 2021). Similarly, our swimmers increased sprint speed along with a small, more negative stroke-timing reorganization (IdC), indicating that performance gains can occur together with specific timing adaptations. By contrast, in the butterfly stroke, elite athletes typically reduce arm–leg timing gaps as pace increases (Seifert et al., 2008). This finding shows that coordination is dynamically linked to velocity, although the direction of change (whether catch-up or overlap) varies depending on the context. Baseline anthropometry did not differ between groups, and weekly training volume was matched. Although post-intervention growth was not tracked, the most plausible explanation for the performance differences is the coordination-focused training (Figueiredo et al., 2016). Our results show that, even at a young age, stroke coordination is a distinct and trainable factor that influences sprint performance (Silva, Figueiredo, Ribeiro et al., 2019).

Practical applications

An approximately 0.21 s advantage over 50 m can affect lane seeding and qualification in age-group meets, where placements are often decided by tenths of a second. This improvement was achieved without increasing total training volume, using brief coordination inserts (about 30 minutes on land and 30 minutes in water, three times per week), scheduled early in the main set with rhythm cues that became progressively more complex. The mean improvement (−0.32 s) exceeded the SWC of approximately 0.28 s, indicating practical relevance.

Conclusion

This study shows that a 12-week combined land–water coordination program can improve 50 m front-crawl sprint performance in young male swimmers without increasing training volume. The improvement resulted mainly from a higher stroke rate, while stroke length did not change significantly. Although the IdC stayed within the catch-up range, a small but statistically significant shift toward more negative values suggests that stroke timing is trainable and can be refined along with changes in stroke tempo.

For coaches, these results support including short, structured coordination drills in regular training to improve competitive readiness during developmental stages. Because the program provides benefits without increasing training volume, it is appropriate for youth training, where maximizing gains while minimizing overload is essential. Future research should include female participants and a wider range of ages, test whether the findings apply to other strokes, and use follow-up assessments to determine if coordination-related gains persist over time.

Limitations

This study has several limitations. First, the sample included only male swimmers aged 11–13 years, which limits generalizability; responses in female swimmers or other age groups may differ because of maturational and hormonal factors. Second, we did not assess retention beyond 12 weeks, so it is unknown whether performance gains with small timing changes (IdC) persist after the program ends. Third, testing used push starts in a 25 m pool; effects may differ under race conditions with dive starts and 50 m pools. Fourth, timekeepers and the video analyst were not blinded, which may introduce measurement bias, even with standardized protocols. Finally, because the protocol combined land- and water-based elements, we cannot determine the independent contribution of each component.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist with English language editing and to improve writing clarity. After using this AI tool, the authors extensively reviewed and edited the content to ensure accuracy and originality, and therefore take full responsibility for the content of this publication.

Conflicts of Interest

The authors declare that they have no competing interests.

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