

Integrated land–water training enhances 200–800 m front-crawl performance in trained youth swimmers

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Abstract:

Efficient stroke coordination under fatigue is a critical determinant of middle-distance performance in youth swimmers; however, integrated land–water training approaches remain insufficiently explored. This randomized controlled trial investigated whether incorporating an integrated land–water training program into regular practice improves 200–800 m front-crawl performance in trained youth swimmers. Thirty-eight trained male swimmers aged 12–13 years were randomly assigned to an experimental group (EG; $n = 19$) or a control group (CG; $n = 19$) for a 12-week in-season intervention. Both groups trained five times·week⁻¹ (~120 min·session⁻¹) with equivalent swim volume. The EG replaced a portion of standard dry-land and technical training with a structured land–water program that combined balance, unilateral stability, and power exercises on land with specific in-water timing and race-pace drills. Performance was evaluated pre- and post-intervention over 200, 400, and 800 m front crawl. Secondary outcomes included stroke rate, stroke length, and inter-arm coordination (Index of Coordination) derived from video analysis. After adjusting for baseline performance, the EG demonstrated significantly greater improvements than the CG across all distances (all $p \leq 0.008$). The adjusted between-group advantage increased with distance: 2.25 s at 200 m, 6.88 s at 400 m, and 11.06 s at 800 m, corresponding to an ~1%–2.5% improvement in the EG versus ~0.5% in the CG. Anthropometric changes were comparable between groups, and no significant between-group differences were observed in stroke kinematics or inter-arm coordination. These findings suggest that incorporating approximately 25–30 min of integrated land–water training per session during the season can significantly improve middle-distance performance in trained youth swimmers without increasing overall training volume.

Keywords: randomized controlled trial, Index of Coordination, stroke kinematics, race-pace training, in-season intervention, age-group swimming

Introduction

Youth swimming performance is a multifactorial phenomenon, with outcomes emerging from the complex interplay of technique, anthropometric development, and physical capacities (Morais et al., 2021; Price et al., 2024). In age-group swimmers, stroke kinematics and coordination are especially important to performance assessment and long-term development (Fiori et al., 2022). However, longitudinal data on technical changes in the youngest swimmers remain scarce, underscoring the importance of systematic technique monitoring in youth cohorts (Jerszyński et al., 2013).

Middle-distance events (200–800 m) are particularly informative because they impose sustained demands on aerobic metabolism, pacing, and the maintenance of technique. Notably, sex-based performance differences are smaller over these distances than in sprint events, highlighting the importance of distance-specific constraints when evaluating training interventions and interpreting 200–800 m outcomes (Ganchar et al., 2025a, 2025b). Aerobic assessment using critical velocity (CV)—typically derived from 200 m and 800 m performances—provides a practical approach for monitoring and prescribing training in young swimmers (Fernandes, 2011), while rapid $\dot{V}O_2$ kinetics are also associated with middle-distance performance (Strzała et al., 2025). Together, these factors emphasize the need for training strategies that concurrently address both the energetic and technical demands of middle-distance swimming. Standardized swim-speed test batteries further support evidence-based monitoring and event-orientation decisions in youth swimmers (Šiljeg et al., 2017).

From a biomechanical perspective, efficient front-crawl performance depends on optimizing the trade-off between propulsion generation and energy expenditure through effective stroke organization (Mullen, 2018). Coordination patterns are not fixed; rather, they function as adaptive strategies that regulate this trade-off across different swimming speeds (Carmigniani et al., 2020). Accordingly, contemporary perspectives view

coordination not as a single optimal pattern, but as a functional outcome emerging from the interaction of organismic, task, and environmental constraints, with multiple effective motor solutions observed even among elite swimmers (Silva, Seifert et al., 2022a; Lin et al., 2025). This framework supports a shift from single-variable analyses toward more integrated, synergy-based approaches to understanding performance (Gao et al., 2025). For developing swimmers, manipulating task constraints (e.g., speed, stroke frequency) can promote coordination flexibility, which is essential for designing effective technique training (Silva et al., 2019).

Dry-land and in-water training components work together to drive these coordinative adaptations. The lower limbs play a crucial role in stabilisation and maintaining a hydrodynamic body position, with specific in-water strength exercises shown to enhance flutter-kicking performance (Mandžák et al., 2020). In contrast, repetitive upper-limb activity can lead to muscle imbalances, highlighting the need for targeted dry-land resistance training as a compensatory strategy (Batalha et al., 2018). Accordingly, age-appropriate strength and conditioning are recommended to reduce injury risk while developing foundational movement skills alongside pool-based training (Nugent et al., 2018). Evidence also indicates that freestyle technique execution is closely related to coordination and strength capacities, supporting the inclusion of coordination-focused programming to improve technical performance (Nikšić et al., 2019). Integrating dry-land core training with in-water practice has been shown to enhance freestyle performance, likely through improvements in core stability and propulsion efficiency (Ratno et al., 2025). Beyond physical loading, young swimmers must continuously adapt and readapt to both physical and psychological stressors; accordingly, monitoring mental, motor, and biochemical indicators can support more individualized planning of training volume and recovery (Mihailescu et al., 2021). In parallel, low-volume, high-intensity approaches have been shown to maintain performance while substantially reducing weekly training time, underscoring the importance of effective training organization and efficiency (Nugent et al., 2019).

Despite this body of knowledge, important gaps remain in the intervention literature for youth swimmers. Most studies have examined isolated components—such as dry-land power (Sadowski et al., 2012), in-water strength (Mandžák et al., 2020), or short-distance coordinative drills (Silva, Figueiredo et al., 2022b)—rather than integrated programs that systematically combine land-based neuromuscular training with specific in-water coordination drills across a training season. Moreover, although a recent randomized controlled trial showed that land–water coordination training improved 50 m sprint performance through changes in stroke rate (SR) (Valijonov et al., 2025), it is unclear whether similar or greater benefits extend to middle-distance events (200–800 m), where pacing and the maintenance of stroke efficiency under fatigue are critical. In addition, there is a lack of randomized controlled trials that simultaneously assess performance, stroke kinematics, and coordination metrics while accounting for growth-related anthropometric changes in trained 12–13-year-old swimmers.

Therefore, this randomized controlled trial aimed to examine the effects of a 12-week integrated land–water training program, incorporated into regular in-season practice, on 200, 400, and 800 m front-crawl performance in trained 12–13-year-old male swimmers, compared with a standard training control group (CG). Secondary objectives were to assess the program's effects on SR, stroke length (SL), and inter-arm coordination [Index of Coordination (IdC)], while accounting for anthropometric changes. We hypothesized that the experimental group (EG) would show greater improvements in middle-distance performance, accompanied by favourable changes in stroke-organization metrics, independent of growth.

This study advances the field by (1) focusing on the under-researched middle-distance range, which presents unique technical and energetic challenges, (2) evaluating a holistic, integrated land–water training program based on contemporary constraint-led theories of motor skill, and (3) providing a comprehensive analysis that links intervention effects on performance, technique, and coordination while accounting for growth.

Materials and methods

Participants

Forty-two healthy, physically active male youth swimmers were recruited and randomly assigned to an EG or a CG using a computer-generated 1:1 allocation sequence, prepared by an investigator independent of training or outcome assessment. Group assignments were concealed until after baseline testing, after which allocation was communicated to the swimmers and their coaches. During the 12-week intervention, two swimmers withdrew owing to injuries unrelated to the study, and two were excluded for failing to meet the pre-defined attendance criterion (<85% of planned sessions). Therefore, 38 swimmers (EG, $n = 19$; CG, $n = 19$; mean age 12.82 ± 0.40 years) completed the intervention and were included in the final per-protocol analyses. In this applied training context, swimmers and coaches were aware of group allocation; however, all primary outcomes were objective, time-based performance measures evaluated under standardized conditions. Training volume, frequency, and testing procedures were strictly matched between groups to minimize expectancy-related bias. The study protocol was approved by the Institutional Research Review Board and performed in accordance with the Declaration of Helsinki (World Medical Association, 2013). Because the participants were minors, written informed consent was obtained from their parents or guardians, and verbal assent was obtained from the swimmers before participation.

An a priori statistical power analysis was performed using G*Power 3 (Faul et al., 2007) for a two-group pre-post design, focusing on the Group×Time effect within a mixed ANOVA/ANCOVA framework. Assuming $\alpha = 0.05$, power $(1-\beta) = 0.80$, and a medium expected effect size (Cohen's $f = 0.25$; Cohen, 1988), the minimum required total sample size was 38 swimmers (19 per group). All participants competed at the national junior level and primarily specialized in 200–800 m freestyle events. The study was performed at the Specialized Children's and Youth Sports School for Water Sports in Tashkent, Uzbekistan.

Inclusion criteria were: (1) male swimmers aged 12–13 years; (2) ≥ 4 years of structured swim training and ≥ 5 sessions·week⁻¹ in the preceding season; (3) no musculoskeletal injury in the previous six months; and (4) no participation in other organized sports during the study period. Exclusion criteria were: (1) lack of parental/guardian consent or swimmer assent; (2) any medical condition contraindicating maximal swimming tests or structured training; (3) current injury or pain at baseline limiting full participation, or any injury/illness during the study that prevented training or testing; (4) attendance below 85% of planned sessions; and (5) failure to complete either pre- or post-intervention testing.

This study used a 12-week, parallel-group, pre-post randomized design, with assessments performed at baseline (Week 1) and post-intervention (Week 13) (Lopes, Jacinto et al., 2025; Espada et al., 2022; Karabıyık et al., 2023). Both groups trained in a 25-m indoor pool five times per week (~ 120 min·session⁻¹). The only planned difference between groups was the content of dryland and selected in-water drills: the EG followed the integrated land–water training program, while the CG continued standard club training without the coordination and resisted-sprint elements.

Table 1. Baseline characteristics of participants by group

Characteristic	CG (Mean $\pm$ SD)	EG (Mean $\pm$ SD)
N	19	19
Sex (male), n (%)	19 (100)	19 (100)
Age (years)	12.83 $\pm$ 0.45	12.82 $\pm$ 0.34
Years of swimming (years)	5.12 $\pm$ 0.99	5.55 $\pm$ 1.09
Height (cm)	158.3 $\pm$ 4.5	159.0 $\pm$ 6.3
Body mass (kg)	48.99 $\pm$ 5.07	49.04 $\pm$ 6.27
BMI (kg/m ²)	19.53 $\pm$ 1.72	19.38 $\pm$ 2.07
Body fat (%)	12.52 $\pm$ 1.52	13.19 $\pm$ 2.84

Notes: Values are presented as mean $\pm$ SD unless otherwise indicated. CG = control group; EG = experimental group.

Outcome measures

The primary outcomes were 200, 400, and 800 m front-crawl time-trial performances, recorded in seconds (s).

The secondary outcomes included SR, SL, and the IdC, all derived from video analysis of mid-pool clean-swim segments. SR was defined as the number of arm stroke cycles per minute (cycles·min⁻¹), SL as the distance covered per stroke cycle (m·cycle⁻¹), and IdC as the percentage temporal gap or overlap between the propulsive phases of the two arms, with negative IdC values indicating a catch-up coordination pattern.

Time-trial protocol

Performance was evaluated through maximal-effort 200, 400, and 800 m front-crawl time trials performed in a 25-m indoor pool. Trials were spread across three separate sessions (one distance per session) with ≥ 24 h between sessions, and the order of distances was randomized. The 200 m trial was performed twice with 30 min of passive recovery, with the best time retained, while the 400 and 800 m trials were completed once each. All sessions were performed at consistent times of day (16:00–18:00) under standardized conditions. Finish times were recorded by two independent timekeepers using handheld digital stopwatches (Seiko S141, Seiko Group Corp., Tokyo, Japan; 0.01 s resolution). If the two times differed by ≤ 0.20 s, their mean was used; if the difference exceeded 0.20 s, the finish was reviewed via high-speed video, and a consensus time was recorded. The video was not used for routine timing. These standardized 25-m pool time trials align with established swim speed test batteries commonly used for profiling and monitoring youth swimmers (Šiljeg et al., 2017).

Design and procedures

Testing was performed in an indoor 25-m pool with water temperature maintained at 27°C–28°C and air temperature at $\sim 28^\circ\text{C}$ – 29°C , in line with World Aquatics recommendations for pool conditions (World Aquatics, 2023). Participants were instructed to maintain their usual routines, avoid participation in other organized sports during the study period, and refrain from strenuous exercise for 24–48 h prior to testing.

Training protocol

Both groups adhered to the same in-season training schedule in a 25-m indoor pool, consisting of five sessions per week, each lasting approximately 120 min. The session structure (including dryland, pool warm-up, main sets, and cool-down) as well as the planned weekly swim volume, was identical for both groups. Weekly distance targets were structured across three mesocycles: technique integration (weeks 1–4: ~ 18 – 21 km·week⁻¹), strength and power (weeks 5–8: ~ 20 – 24 km·week⁻¹), and performance realization (weeks 9–12: ~ 16 – 20 km·week⁻¹). Training distances were planned and monitored using coach logs, with no systematic between-

group differences in total weekly swim distance observed. This overall load aligns with weekly volumes reported for age-group swimmers around 12 years performing $\sim 4\text{--}5$ sessions $\cdot\text{week}^{-1}$ (Ferreira et al., 2021). Coaches also aimed to maintain a broadly similar intensity distribution between groups, balancing proportions of low-, moderate-, and high-intensity swimming.

The CG followed their usual swim school program as designed by the team coach. This included standard pool sets for 200–800 m swimmers, combining aerobic, threshold, and race-pace work, along with 20–30 min of routine dryland exercises at the start of each session (general core, flexibility, and basic strength exercises). No specific coordination-focused drills (e.g., structured timing drills such as 6-1-6 or single-arm snorkel exercises) or resisted sprint sets (e.g., elastic cord/tether work) were included beyond the club's standard technical and pacing content. Race-pace work for 200–800 m events was incorporated into the main pool sets for both groups as part of the standard in-season program, rather than being uniquely added for the EG.

The EG completed the same overall swim volume and main pool sets as the CG, but in each session, $\sim 25\text{--}30$ min of the usual dryland and part of the technical drill block were replaced with an integrated land–water training module. This module combined land-based antirotation, unilateral stability, and power exercises with specific in-water coordination drills and race-pace sets, progressing across three 4-week mesocycles: technique integration, strength and power, and performance realization. Accordingly, the intervention represents a coordinated, multi-component modification in the delivery of neuromuscular and race-pace load, rather than an increase in overall training volume or frequency, or a "pure" coordination drill block performed in isolation. The program's structure and dosage are summarized in Table 3, with detailed exercise descriptions provided in Supplementary Table S1. All EG sessions were supervised by members of the research team to ensure correct execution and target intensity. Attendance was recorded for both groups, and only swimmers who attended $\geq 85\%$ of planned sessions were included in the final analyses.

Table 2. Typical structure and planned duration of a training session for both groups

Component	Duration	Primary focus
Dryland	25–30 min	Neuromuscular preparation, core stability, and general strength/flexibility
Transition	~ 5 min	Transition from deck to water; maintaining readiness
In-water training	85–90 min	In-water volume $\sim 2\text{--}4$ km $\cdot\text{session}^{-1}$; technique and race-pace sets (including warm-up and cool-down).

Notes: Durations are approximate and reflect the planned session template (~ 120 min). The session structure and total time were similar between groups; only the content of dry-land and selected in-water drills differed (see Table 3).

Table 3. Experimental group's integrated land–water training program over three 12-week mesocycles

Mesocycle (weeks)	Land block (25–30 min): primary targets and drill library	Land dosage (reported)	In-water block (85–90 min): primary targets and examples	In-water dosage (sets $\times$ distance; rest) + weekly volume (reported)
1 (Weeks 1–4) Technique integration	Trunk stiffness, unilateral balance control, and inter-limb coordination to stabilize body alignment and timing. Land drills and exercise IDs: L1–L2, L7–L8, L10 (see Supplementary Table S1)	2–3 sets per drill; 6–10 repetitions or 20–30 s; rest 30–60 s; RPE 5–6/10	Coordination and rhythm control using technical constraints (snorkel-based timing, single-arm control, sculling/feel), combined with tempo-controlled short repeats. In-water drill IDs: W1–W3 (see Supplementary Table S1)	Drills: $6\text{--}10 \times 15\text{--}25$ m; rest 20–40 s. Tempo sets: $4\text{--}8 \times 25\text{--}50$ m at prescribed stroke tempo; rest 30–45 s. Target volume: $\sim 18\text{--}21$ km $\cdot\text{week}^{-1}$
2 (Weeks 5–8) Strength and power	Reactive unilateral power, lateral stability, and high-frequency coordination under faster ground contacts. Land drills and exercise IDs: L3–L6, L9 (see Supplementary Table S1)	3–4 sets per drill; 4–8 repetitions (explosive) or 15–25 s; rest 60–120 s; RPE 7–8/10	Resisted speed development and power endurance while preserving stroke timing (e.g., short resisted sprints using an elastic cord or tether, race-pace short repetitions)	Resisted sprints: $6\text{--}10 \times 10\text{--}20$ m; rest 45–90 s (resistance individualized to maintain stroke mechanics). Power-endurance: $6\text{--}10 \times 50$ m; rest 30–45 s (≥ 1 set $\cdot\text{week}^{-1}$). Target volume: $\sim 20\text{--}24$ km $\cdot\text{week}^{-1}$
3 (Weeks 9–12) Performance realization	Maintain neuromuscular quality while reducing land-based volume (taper-like) and preserving coordination under fatigue. Land drills and exercise IDs (reduced dose): L3–L4, L6, L8–L10 (see Supplementary Table S1)	Reduce land volume by $\sim 20\%\text{--}40\%$; 2–3 sets per drill; 4–6 repetitions or 15–25 s; rest 45–90 s; RPE 6–7/10.	Race-pace integration for 200–800 m using structured broken swims and pace-control sets, with rehearsal of stable stroke timing at target speeds.	Race-pace exposures: 1–2 sessions $\cdot\text{week}^{-1}$ with predefined reps $\times$ distance $\times$ rest (e.g., broken 200 s; 100/200 pace work; negative-split 500). Endurance anchor: 1 session $\cdot\text{week}^{-1}$. Target volume: $\sim 16\text{--}20$ km $\cdot\text{week}^{-1}$

Notes: Swimmers trained five sessions·week⁻¹ in a 25-m pool (~120 min·session⁻¹). The EG performed a standardized 25–30 min land-based training block integrated into each session, followed by an 85–90 min in-water workout. Weekly swim volume was planned and monitored using coach training logs. Detailed descriptions, coaching cues, and progression/regression guidelines for land exercises (L1–L10) and in-water drills (W1–W3) are provided in Supplementary Table S1. Abbreviations: EG, EG; RPE, rating of perceived exertion (CR10 scale)

Video analysis and variable computation

As demonstrated by Mooney et al. (2015), video analysis is a widely used method for performance assessment in competitive swimming. In this study, video-based technical analysis was performed using a dual-camera setup, consistent with prior multi-camera approaches for evaluating swimming performance and technique in youth swimmers (Jerszyński et al., 2013). Trials were recorded with two GoPro HERO12 Black cameras (GoPro, Inc., San Mateo, CA, USA) positioned to minimize parallax error: an underwater camera (2.7K, 120 fps) mounted on a weighted tripod 1.0 m below the surface and 12.5 m from the wall, perpendicular to the swimming direction, and an above-water camera (4K, 120 fps) mounted 1.5 m above the deck, angled approximately 15° downward. Because underwater imaging is affected by refraction through the housing port and water medium, rigid mounting and calibration are essential for accurate spatial measurements; accordingly, a 1-m underwater scale was used for spatial calibration (Shortis, 2015). Video footage was digitized frame by frame in Kinovea (version 0.9.5; Kinovea Team, 2021) across six to eight consecutive mid-pool clean-swim stroke cycles, excluding starts and turns. All analyses were performed by a single investigator trained in the segmentation protocol, using standardized anatomical landmarks and event definitions to minimize rater-dependent error. The segmentation procedure and IdC calculation followed previously established front-crawl protocols, which have demonstrated acceptable intra- and inter-rater reliability for stroke-phase and coordination measures in both youth and adult swimmers (Silva et al., 2012; Schnitzler et al., 2009; Silva et al., 2022). Although measurement error was not separately quantified in this sample, the kinematic and IdC variables used here are consistent with validated, widely used video-analysis methods in competitive swimming.

Stroke cycles were divided into entry/catch, pull, push, and recovery phases using predefined key events (Silva et al., 2012). For inter-arm coordination analysis, each stroke cycle was segmented following Chollet et al. (2000): (i) entry and catch (hand entry to maximal forward displacement), (ii) pull (maximal forward displacement to when the hand passes beneath the shoulder), (iii) push (end of the pull to hand exit), and (iv) recovery (hand exit to re-entry). Pull and push phases were classified as propulsive, while entry–catch and recovery were considered non-propulsive. Phase durations were obtained for two successive arm strokes through frame-by-frame digitization, and IdC (%) was calculated based on the temporal gap or overlap between the propulsive phases of the two arms (Chollet et al., 2000). Because coordination metrics and stroke-phase timing can be reliably assessed from short race-pace segments (Schnitzler et al., 2009), IdC estimation was standardized by analyzing only mid-pool clean-swim cycles with a consistent breathing pattern and by excluding starts and turns, in line with established IdC-focused protocols (Valkoumas et al., 2020).

SR and SL were derived from video analysis using standard definitions (Nasirzade et al., 2015). SR was calculated as $SR = 60 / \text{stroke-cycle time}$ and expressed in cycles·min⁻¹. SL was calculated as $SL = v / (SR / 60)$, where v is the swimming velocity for the analyzed mid-pool segment, and expressed in m·cycle⁻¹. Swimming velocity (v) was determined from the time taken to cover a fixed 10-m mid-pool distance synchronized with the analyzed clean-swim segment, excluding starts and turns. All time trials began with a track start under consistent instructions, and each swimmer used their habitual start technique at both pre- and post-testing. All technical outcomes (SR, SL, and IdC) were obtained from these same standardized mid-pool segments.

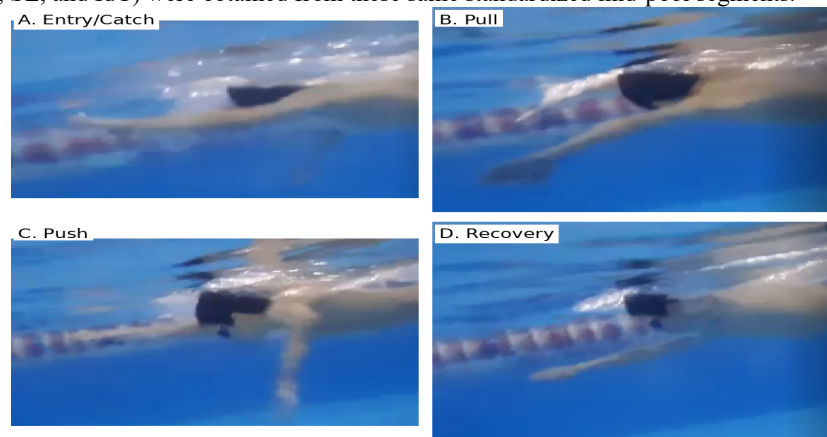


Fig. 1. Representative underwater frames from the analyzed clean-swim segment illustrating the front-crawl stroke phases used for video-based segmentation: (A) entry/catch, (B) pull, (C) push, and (D) recovery. Phases

were identified using predefined key events (Silva et al., 2012; Chollet et al., 2000) and applied consistently across all analyzed stroke cycles.

Anthropometrics and body composition

Standing height and body mass were measured at baseline and post-intervention under standardized conditions (same time of day, barefoot, wearing light clothing). Body mass was recorded to the nearest 0.1 kg using a calibrated digital scale (KINLEE, TCS-200MLA; maximum capacity 200 kg), and standing height was measured to the nearest 0.1 cm with a stadiometer. Body mass index (BMI) was calculated as $\text{kg}\cdot\text{m}^{-2}$ (body mass/height²). Body fat percentage was assessed via bioelectrical impedance analysis (Tanita Corporation, MC-780U PLUS, Tokyo, Japan) under standardized conditions, including preprandial measurement, controlled hydration, and avoidance of strenuous exercise for 24 h, using identical device settings at both time points.

Statistical analysis

All statistical analyses were performed using JASP (version 0.19.3; JASP Team, 2025), with significance set at $\alpha = 0.05$. For primary outcomes (200, 400, and 800 m front-crawl performance) and technical stroke measures (SR, SL, and IdC), between-group effects were evaluated using ANCOVA, with post-intervention values as the dependent variable, Group (EG vs. CG) as the fixed factor, and baseline values as the covariate. This method accounts for baseline variability and provides greater statistical power than change-score analyses in randomized designs (Vickers & Altman, 2001; Van Breukelen, 2006). Anthropometric and body composition outcomes were analyzed using two-way mixed ANOVAs (Group $\times$ Time). Effect sizes were reported as partial eta squared (η^2) and interpreted according to Cohen's guidelines (0.01 = small, 0.06 = medium, and 0.14 = large). Model assumptions (including normality, homogeneity of variance, and homogeneity of regression slopes for the ANCOVA models) were checked using residual diagnostics, and no violations were detected. Residual and influence diagnostics revealed no swimmers as outliers exerting undue influence on model estimates. The confirmation of homogeneous slopes supports the use of baseline-adjusted ANCOVA, despite observable numerical differences at baseline (e.g., in 800-m performance).

Confidence intervals (95% CI) were reported for adjusted mean differences where applicable. Post hoc tests were adjusted using the Bonferroni correction when required. Because the intervention was specifically designed to target the middle-distance range rather than a single event, the three performances (200, 400, and 800 m) were treated as pre-specified co-primary outcomes, each with practical relevance for coaches and athletes. Accordingly, no multiplicity correction was applied across these distances. Stroke kinematic variables (SR, SL, and IdC) were considered secondary/exploratory outcomes and interpreted with caution. Given the correlated nature of the three distances and consistently low p-values for performance (all $p \leq 0.008$), it is unlikely that the main findings are attributable only to multiple testing.

Results

Baseline characteristics were broadly similar between groups (Table 1), indicating that randomization yielded comparably matched groups at study entry.

Anthropometric and body composition outcomes

Over the 12-week period, both groups exhibited the expected growth-related changes (Table 4). A significant main effect of Time was observed for all anthropometric variables: height (EG: +1.3 cm; CG: +1.8 cm), body mass (EG: +0.25 kg; CG: +0.35 kg), BMI (EG: $-0.21 \text{ kg}\cdot\text{m}^{-2}$; CG: $-0.29 \text{ kg}\cdot\text{m}^{-2}$), and body fat percentage (EG: -0.96% ; CG: -0.59%) (all $p \leq 0.006$). No significant Group $\times$ Time interactions were found for any variable (all $p \geq 0.072$), indicating that changes in anthropometry and body composition occurred similarly across groups. These results suggest that the performance differences observed between EG and CG are unlikely to be attributable to differential growth or maturation effects.

Table 4. Pre–Post changes in anthropometrics and body composition with mixed (Group $\times$ Time) ANOVA effects (n = 38)

Variable	CG Pre (M $\pm$ SD)	CG Post (M $\pm$ SD)	CG ($\Delta\%$)	Δ	EG Pre (M $\pm$ SD)	EG Post (M $\pm$ SD)	EG ($\Delta\%$)	Δ	Group $\times$ Time (F(1,36), p, η^2)	Time (F(1,36), p, η^2)
Height (cm)	158.3 $\pm$ 4.5	160.1 $\pm$ 4.6	1.8 (1.14%)		159.0 $\pm$ 6.3	160.3 $\pm$ 6.1	1.3 (0.82%)		F = 3.44, p = 0.072, η^2 = 0.087	F = 142.73, p < 0.001, η^2 = 0.799
Body mass (kg)	48.99 $\pm$ 5.07	49.34 $\pm$ 4.88	0.35 (0.71%)		49.04 $\pm$ 6.27	49.29 $\pm$ 6.33	0.25 (0.51%)		F = 0.23, p = 0.637, η^2 = 0.006	F = 8.62, p = 0.006, η^2 = 0.193
BMI (kg/m ²)	19.53 $\pm$ 1.72	19.24 $\pm$ 1.65	-0.29 (-1.49%)		19.38 $\pm$ 2.07	19.17 $\pm$ 2.14	-0.21 (-1.08%)		F = 0.64, p = 0.428, η^2 = 0.018	F = 23.73, p < 0.001, η^2 = 0.397
Body fat (%)	12.52 $\pm$ 1.52	11.93 $\pm$ 1.79	-0.59 (-4.71%)		13.19 $\pm$ 2.84	12.23 $\pm$ 2.93	-0.96 (-7.28%)		F = 1.34, p = 0.255, η^2 = 0.036	F = 23.34, p < 0.001, η^2 = 0.393

Notes: Values are presented as mean $\pm$ SD. CG = control group; EG = experimental group. Δ = Post – Pre; $\Delta\%$ = (Δ /Pre) $\times$ 100 (calculated from group means). Reported mixed-design ANOVA effects include Group $\times$ Time

(interaction) and Time (main effect). η^2 = partial eta squared. Height values are rounded to one decimal place (cm) for manuscript reporting.

Performance outcomes (200, 400, and 800 m)

Descriptive baseline performance data are shown in Table 5. Independent samples t-tests indicated no statistically significant between-group differences at baseline for any distance (all $p > 0.05$); however, the EG was numerically slower, with the largest difference observed in the 800 m trial (mean difference ≈ 30 s). Therefore, the subsequent ANCOVA models, which adjust for baseline values, provide the appropriate method for evaluating intervention effects.

After adjusting for baseline performance using ANCOVA, the EG showed significantly greater improvements than the CG across all three distances (all $p \leq 0.008$, partial $\eta^2 = 0.18$ – 0.35 ; Table 5; Figure 2). The adjusted between-group advantage increased with distance: 2.25 s at 200 m, 6.88 s at 400 m, and 11.06 s at 800 m. At 800 m, the EG substantially reduced (but did not fully eliminate) the baseline performance gap; their raw post-test time remained slightly slower than that of CG (755.6 ± 107.8 s vs. 736.5 ± 72.3 s), yet the baseline-adjusted model indicated a significantly greater improvement over the 12-week intervention. In relative terms, the EG improved by approximately 1%–2.5% across the three distances, compared with $\sim 0.5\%$ in CG, demonstrating a meaningful impact of the integrated land–water training program.

As shown in Figure 2, the EG demonstrated consistently greater percentage improvements in race time than the CG across all distances. Mean improvements for EG were 1.8%, 2.4%, and 1.8% at 200, 400, and 800 m, respectively, compared with 0.6%, 0.5%, and 0.4% in CG. This pattern visually reinforces the baseline-adjusted ANCOVA results, highlighting that the largest relative advantage of the integrated land–water training program occurred at the 400–800 m distances.

Table 5. Pre- and post-intervention performance and ANCOVA-adjusted between-group differences for 200-, 400-, and 800-m front crawl

Distance	CG PRE (s) Mean $\pm$ SD	CG POST (s) Mean $\pm$ SD	EG PRE (s) Mean $\pm$ SD	EG POST (s) Mean $\pm$ SD	Adjusted advantage (s) (EG vs. CG)	95% CI	F(1,35)	p	η^2
200 m	174.35 $\pm$ 14.46	173.39 $\pm$ 14.72	175.05 $\pm$ 20.91	171.83 $\pm$ 20.37	2.25	0.62 to 3.88	7.894	0.008	0.184
400 m	365.47 $\pm$ 32.41	363.51 $\pm$ 33.09	366.59 $\pm$ 50.82	357.78 $\pm$ 52.48	6.88	3.52 to 10.24	17.264	<0.001	0.330
800 m	739.76 $\pm$ 69.66	736.51 $\pm$ 72.34	769.03 $\pm$ 104.70	755.57 $\pm$ 107.79	11.06	5.91 to 16.20	19.051	<0.001	0.352

Notes: Values are presented as mean $\pm$ SD. ANCOVA was used to compare post-intervention performance between groups, adjusting for pre-test time as a covariate. The "Adjusted advantage (EG vs. CG)" column represents the baseline-adjusted between-group difference in seconds, with positive values indicating faster performance (lower time) in the EG. Overall, the adjusted between-group differences increased with distance, reflecting the greatest practical benefit for middle-distance performance. Adjusted advantage reflects the baseline-adjusted difference estimated at a common baseline value (estimated marginal means) and does not necessarily correspond to the raw post-test difference.

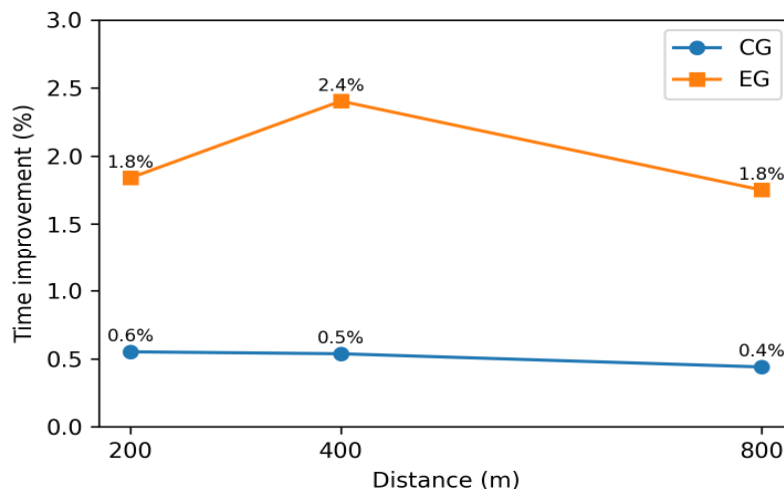


Figure 2. Percentage change in 200, 400, and 800 m front-crawl performance after the 12-week intervention for the CG and EG. Values represent mean percentage improvements in race time; positive values indicate faster post-intervention performance (shorter times).

Stroke mechanics and index of coordination (IdC)

Stroke mechanics (SR and SL) and the Index of Coordination (IdC) remained largely stable over the 12-week intervention in both groups (Table 6, Figure 3). After adjusting for baseline values using ANCOVA, no statistically significant between-group differences were observed for post-test SR, SL, or IdC across 200, 400, or 800 m (all $p \geq 0.085$, $\eta^2 \leq 0.082$).

For SR, p -values ranged from 0.085 to 0.940, with no meaningful between-group differences in cadence. SL similarly showed no significant between-group differences (all $p \geq 0.448$), with small effect sizes.

IdC values remained negative across all distances, indicating that both groups retained a catch-up coordination pattern throughout the study. Small shifts toward less negative IdC (i.e., slightly reduced catch-up) were observed from pre- to post-test in both EG and CG. For instance, at 200 m, EG changed from $-5.11\% \pm 6.61\%$ to $-4.05\% \pm 6.62\%$, while CG changed from $-4.05\% \pm 6.02\%$ to $-3.31\% \pm 6.17\%$ (group effect $p = 0.544$). Similar non-significant trends were observed at 400 m ($p = 0.335$) and 800 m ($p = 0.442$).

Overall, the EG showed slightly larger pre-post improvements in coordination indices, but these changes were not statistically significant. The notable performance gains in EG thus appear to have been achieved without major detectable changes in SR, SL, or IdC, suggesting that improvements may reflect more subtle adaptations in whole-body coordination and race-pacing strategy.

Table 6. Stroke rate, stroke length, and index of coordination at pre- and post-intervention for control and experimental groups, with ANCOVA p -values and partial eta squared

Variable	Distance	CG PRE (Mean $\pm$ SD)	CG POST (Mean $\pm$ SD)	EG PRE (Mean $\pm$ SD)	EG POST (Mean $\pm$ SD)	ANCOVA p	η^2
SR (cycles·min ⁻¹)	200 m	38.16 $\pm$ 3.65	38.04 $\pm$ 3.68	38.89 $\pm$ 5.30	38.66 $\pm$ 5.31	0.085	0.082
SR (cycles·min ⁻¹)	400 m	37.25 $\pm$ 3.24	37.60 $\pm$ 3.69	37.83 $\pm$ 8.08	37.63 $\pm$ 8.01	0.887	0.001
SR (cycles·min ⁻¹)	800 m	39.28 $\pm$ 4.98	39.13 $\pm$ 4.95	39.50 $\pm$ 5.94	39.01 $\pm$ 5.92	0.940	0.000
SL (m·cycle ⁻¹)	200 m	1.81 $\pm$ 0.12	1.84 $\pm$ 0.11	1.82 $\pm$ 0.13	1.84 $\pm$ 0.13	0.920	0.000
SL (m·cycle ⁻¹)	400 m	1.78 $\pm$ 0.14	1.78 $\pm$ 0.15	1.86 $\pm$ 0.19	1.84 $\pm$ 0.18	0.704	0.004
SL (m·cycle ⁻¹)	800 m	1.67 $\pm$ 0.16	1.69 $\pm$ 0.16	1.61 $\pm$ 0.12	1.66 $\pm$ 0.09	0.448	0.017
IdC (%)	200 m	-4.05 $\pm$ 6.02	-3.31 $\pm$ 6.17	-5.11 $\pm$ 6.61	-4.05 $\pm$ 6.62	0.544	0.011
IdC (%)	400 m	-4.92 $\pm$ 5.43	-4.35 $\pm$ 5.52	-4.63 $\pm$ 4.91	-3.52 $\pm$ 5.19	0.335	0.026
IdC (%)	800 m	-4.16 $\pm$ 4.20	-3.85 $\pm$ 4.31	-4.74 $\pm$ 4.22	-3.89 $\pm$ 4.24	0.442	0.017

Notes: Values are mean $\pm$ SD. ANCOVA compares post-intervention values between groups, adjusted for pre-intervention (baseline) values as a covariate. SR = stroke rate; SL = stroke length; IdC = index of coordination

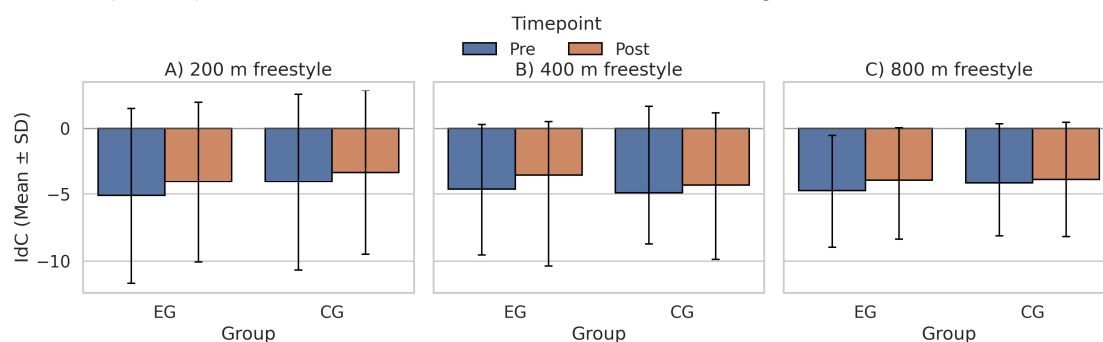


Figure 3. Index of coordination (IdC) at 200 m (Panel A), 400 m (Panel B), and 800 m (Panel C) for control and experimental groups, pre- and post-intervention. Error bars represent standard deviations. ANCOVA showed no significant between-group differences after adjusting for baseline ($p > 0.05$ for all)

Discussion

This randomized controlled trial showed that a 12-week integrated training program (combining land-based stability and power exercises with specific in-water coordination drills and race-pace sets) produced significantly greater improvements in 200–800 m front-crawl performance compared with standard in-season training. Although the EG was numerically slower at baseline, particularly in the 800 m event, ANCOVA was used to adjust for these initial differences. The homogeneity-of-regression-slopes assumption was met, supporting the validity of these baseline-adjusted between-group comparisons (Vickers & Altman, 2001; Van Breukelen, 2006). Therefore, the observed adjusted advantages represent meaningful performance benefits attributable to the integrated training intervention rather than baseline imbalances or statistical artifacts.

Improvements increased with distance, indicating that the intervention had its greatest practical effect on middle-distance events (400–800 m).

From a constraints-led perspective, front-crawl coordination is not a single "ideal" pattern but rather an adaptive response to the interaction of organismic, task, and environmental constraints (Silva, Seifert et al., 2022a). Low-speed catch-up coordination (often representing a burst-and-coast strategy) can optimize the balance between propulsion and energy expenditure, particularly at moderate intensities (Carmigniani et al., 2020). This framework helps explain how swimmers with different constraints can achieve similar race paces using distinct inter-limb coordination patterns (Yang et al., 2024). At controlled distance paces, sprint and distance specialists exhibit minimal kinematic differences (McCabe & Sanders, 2012), highlighting that effective coordination solutions are highly individual and context-specific.

Within this framework, the lack of between-group differences in SR, SL, and IdC does not contradict the observed performance improvements; rather, it reflects the relative sensitivity of these measures to the mechanisms most likely influenced by the intervention. Three complementary explanations are relevant. First, SR, SL, and IdC were calculated from mid-pool clean-swim segments at a single point in each trial—a methodological convention that captures average stroke organization under relatively non-fatigued conditions but does not detect coordination deterioration during the latter stages of 400–800 m races. The primary competitive challenge in middle-distance events is maintaining stroke timing under progressive fatigue, rather than altering the mean mid-race values. If the integrated land–water program primarily enhanced the robustness of each swimmer's individual coordination pattern under fatigue rather than changing its mean value, the current measurement protocol would be inherently insensitive to this adaptation. This aligns with the constraints-led perspective, which emphasizes that effective training stabilizes a functional solution in task constraints rather than enforcing convergence toward a normative pattern (Silva, Seifert et al., 2022a; Silva et al., 2019; Seifert et al., 2016). Second, the land-based component of the intervention (comprising anti-rotation exercises, unilateral stability drills, and core-stiffness work) specifically targeted trunk rigidity and bodyline control, capacities that directly influence body alignment and frontal projected area in the water. Prior experimental work demonstrates that active and passive drag coefficients are highly sensitive to postural changes, even when stroke frequency and coordination indices remain unchanged (Lopes et al., 2025), providing a biomechanically plausible pathway linking the land-based training components to the observed performance improvements. Third, the intervention may have improved stroke economy (defined as the metabolic energy required to maintain a given stroke pattern at race velocity) because swimmers can achieve faster speeds at the same mean SR and SL if the neuromuscular cost per cycle is reduced (Barbosa et al., 2010). Because hydrodynamic variables and oxygen-uptake kinetics were not directly measured in this study, all three proposed mechanisms remain inferential and should be treated as hypotheses for future research. Importantly, each of these pathways could lead to faster race times without changing the mean SR, SL, or IdC values measured at mid-pool under non-fatigued conditions, thereby reconciling the apparent discrepancy between the observed performance gains and the stable stroke kinematics.

The observed performance gains are consistent with previous research indicating that swimmers' coordination profiles and propulsion patterns can be modified through race-pace exposure and targeted constraint manipulations (Silva, Figueiredo et al., 2022b). Our program incorporated race-pace training at intensities of approximating 95%–110% of CV for this age group, aligning with reports that CV-based training more effectively enhances middle-distance performance in ~13-year-old swimmers when training volume is controlled (Tijani et al., 2022). Additionally, race-pace volume, technical drill content, and recovery distribution have been identified as key predictors of middle-distance performance in retrospective analyses (Guzman & Brođani, 2025). Unlike interventions focusing only on dry-land power development (Sadowski et al., 2012), which increased tethered force but showed limited transfer to sprint performance, our findings suggest that coordinative specificity (linking dry-land and in-water components) is crucial for meaningful performance improvements. Real-time feedback tools may further support this process by helping correct inter-limb asymmetries during arm propulsion (Abdulghani et al., 2025).

Although pacing profiles were not directly monitored in this study, the progressively larger adjusted performance advantage with distance (from 2.25 s at 200 m to 11.06 s at 800 m) supports a fatigue-resistance interpretation rather than a pure speed effect. Analyses of international championships have shown U-shaped pacing in 800–1500 m freestyle, with frequent micro-variations indicative of fatigue-related stroke disruptions (Demarie et al., 2023), highlighting the importance of maintaining stroke stability under fatigue—a target explicitly addressed by our integrated land–water training program. Moreover, performance gains during adolescence are influenced by both training and growth-related factors. Seasonal improvements in young swimmers have been associated with increased stroke index and hand force output, alongside anthropometric development (Costa Santos et al., 2024). By controlling for anthropometric growth, our study reinforces that the observed performance improvements are attributable primarily to the training intervention rather than maturation alone. Finally, although general motor-learning principles suggest that coordination-focused interventions may produce larger relative gains in less-experienced athletes (Morrow et al., 2015), our findings show that even trained youth swimmers can benefit from integrated land–water training. A volume-manipulated 12-week interval program has also been shown to improve 50–800 m performance and stroke metrics in youth (Karabiyik et al., 2023), supporting the feasibility of moderate-volume, high-specificity training programs. Our results

extend this body of work by simultaneously addressing both biomechanical and physiological aspects of middle-distance performance in trained young swimmers. Moreover, meta-analytic data indicate that 400-m front crawl is typically performed at a mean speed of $\sim 1.34 \text{ m}\cdot\text{s}^{-1}$, with stroke efficiency of $\sim 35\%$ and predominantly catch-up coordination ($\text{IdC} \approx -11\%$) (Correia et al., 2023). Training tools (such as paddles and fins) have been shown to influence stroke timing, IdC values, and energetic cost, underscoring their role in promoting neuromuscular adaptations relevant to integrated land–water training (de Matos et al., 2023). Taken together, this literature supports the principle that middle-distance performance in youth swimmers can be enhanced through targeted interventions that stabilize and optimize individual stroke organization under task-specific constraints, rather than enforcing a single, universal technical model.

Conclusions

This randomized controlled trial demonstrates that incorporating a structured 12-week land–water training program into regular in-season practice effectively improves middle-distance (200–800 m) front-crawl performance in trained 12–13-year-old male swimmers. After adjusting for anthropometric changes, these performance gains occurred without substantial changes in standard stroke kinematics, suggesting improvements in overall performance organization under fatigue—potentially via enhanced hydrodynamic alignment, improved core stability, or more consistent race pacing. These proposed mechanisms were not directly measured and should be considered hypotheses for future investigation.

From a practical standpoint, coaches could allocate approximately $25\text{--}30 \text{ min}\cdot\text{session}^{-1}$ to land-based stability and power exercises that are directly integrated with in-water coordination drills and race-pace sets. This approach aligns with a constraints-led framework, emphasizing optimization of the swimmer's interaction with task and environmental demands rather than enforcing a single rigid technical model. By reorganizing existing training time to prioritize this integrated land–water content, meaningful performance gains can be achieved without increasing overall training volume.

The study has several limitations. It focused only on male swimmers within a narrow age range from a single training center, and did not include detailed physiological or pacing measurements. The intervention period was relatively short (12 weeks). Biological maturation (e.g., Tanner stage or proximity to peak height velocity) was not directly assessed; although both groups exhibited very similar changes in height, body mass, BMI, and body fat, small between-group differences in maturation could still have contributed to variability in performance adaptations. Additionally, as is typical in applied youth sport research, participants and coaches were aware of group allocation, which may have influenced outcomes. The use of objective performance measures and matched training volume across groups reduces the likelihood that expectancy effects fully account for the observed between-group differences. However, modest motivational or Hawthorne effects associated with participating in a novel program cannot be entirely excluded (Adair, 1984). It also remains unclear whether the performance gains were driven primarily by neuromuscular adaptations from the integrated land–water training or by the additional emphasis on race-pace and resisted in-water sets. Because the experimental intervention deliberately combined land-based stability and power exercises with additional race-pace and resisted in-water sets, the trial was not designed to isolate the specific contribution of integrated land–water training from other neuromuscular and race-specific adaptations. Future research should investigate the efficacy of similar programs in female swimmers, other age groups, and higher performance levels, incorporating measures such as pacing profiles, oxygen-uptake kinetics, and force production to clarify underlying mechanisms. Longitudinal studies are also needed to determine how integrated land–water training affects the long-term developmental trajectory of middle-distance performance in youth swimmers.

Declaration of use 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 enhance writing clarity. Following the use of this AI tool, the authors thoroughly reviewed and revised the content to ensure accuracy and originality, and thus 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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Supplementary table S1. Consolidated exercise library for the integrated land–water training intervention (experimental group)

ID	Exercise (modality)	Primary coordination target	Setup equipment	Key coaching cues (quality criteria)	Typical dose (M1 → M2 → M3)	Progression regression	Mesocycle use
L1	Single-leg airplane (land)	Unilateral balance; hip-hinge control; trunk anti-rotation	Flat surface; optional light load (0.5–2 kg)	Tripod foot; hinge at hip (flat back); control pelvis (no twist)	2 × 6–8/side (3 s hold) → 3 × 6/side (slower ecc.) → 2 × 5/side (quality)	Prog: eyes closed or reach to targets; add load. Reg: fingertip support; smaller hinge range	M1–M3
L2	Single-leg clock reach / toe-touch around foot (land)	Dynamic balance; proprioception; ankle-knee-hip alignment	Flat surface; cones/marks optional	Soft knee; knee tracks over second toe; controlled reach to 3–5 points	2 × 3 rounds/side → 3 × 3 rounds/side (faster reach) → 2 × 2 rounds/side	Prog: add mini-hops between points. Reg: fewer points; hand support	M1–M3
L3	One-foot hop (forward) (land)	Reactive stiffness; single-leg SSC; rhythm	Flat surface; marked distance optional	Quiet landing; stable knee; quick ground contact	2 × 6–8/leg → 3 × 6/leg (faster) → 2 × 5/leg (quality)	Prog: longer distance or reduced contact time. Reg: submaximal hops; stick landings	M2 (+M3 reduced)
L4	One-foot lateral hop (land)	Frontal-plane control; hip-knee	Flat surface; line marker optional	Hips level; knee over toe; avoid valgus collapse	2 × 6–8/leg → 3 × 6/leg → 2 × 5/leg	Prog: wider hops; reactive (no pause). Reg: shorter hops;	M2 (+M3 reduced)

		alignment; agility				pause and stabilize	
L5	One-foot square jump (land)	Multi-directional coordination; spatial orientation	Four markers arranged as a small square	Land softly; maintain trunk control; consistent rhythm	1–2 rounds/square → 2–3 rounds → 1–2 rounds (taper)	Prog: larger square / faster rhythm. Reg: two-foot pattern first	Optional (late M2–M3)
L6	Ball skip / skip around target (land)	Rhythm; footwork coordination; dynamic balance	Small cone/ball target	Upright posture; light contacts; smooth direction change	2 × 20–30 s → 3 × 20–30 s → 2 × 15–20 s	Prog: faster cadence; smaller circle. Reg: march pattern around the target	M2–M3
L7	Crawl switch under (land)	Cross-body coordination; shoulder-core integration	Mat/flat surface	Active shoulders; hips stable; controlled switch under body	2 × 6–8 switches → 3 × 6–8 → 2 × 5–6	Prog: faster switch; longer lever. Reg: slow march-like transitions	M1–M2 (maintained at low dose in M3)
L8	Side high plank (land)	Lateral trunk endurance; shoulder stability	Mat	Straight line head–hip–ankle; shoulders stacked; no hip drop	2 × 20–30 s/side → 3 × 20–30 s → 2 × 15–25 s	Prog: add reach/rotation. Reg: knees down	M1–M3
L9	Star plank (side plank + top-leg lift) (land)	Lateral chain + hip abductor control; anti-rotation	Mat	Lift top leg without trunk rotation; pelvis level	1–2 × 6–10 lifts/side → 2–3 × 6–10 → 1–2 × 5–8	Prog: longer hold at top; add ankle weight. Reg: shorten lever; no leg lift (use L8)	M2–M3
L10	Flying flamingo (single-leg balance + alternate arm raises) (land)	Postural control; inter-limb coordination; balance under arm motion	Flat surface; optional foam block	Tall posture; knee up; maintain core tension during arm alternation	2 × 20–30 s/side → 3 × 20–30 s → 2 × 15–20 s	Prog: eyes closed or unstable surface. Reg: lower knee or hold support	M1–M3
W1	6-1-6 drill (snorkel optional) (water)	Rotation timing; streamline stability; rhythm	Snorkel recommended; pull buoy optional	Long bodyline; stable head; timed switch at hip rotation	4–8 × 25 m → 6–10 × 25 m → 4–6 × 25 m	Prog: add tempo constraint. Reg: shorter distance (12.5 m)	M1 (maintain as a primer in M2–M3)
W2	Single-arm freestyle (snorkel + ankle band optional) (water)	Propulsion symmetry; catch timing; trunk stability	Snorkel; optional ankle band/pull buoy	Quiet hips; stable kick (or band); complete catch–pull path	4–8 × 25 m/arm → 6–10 × 25 m/arm → 4–6 × 25 m/arm	Prog: tempo-controlled repetitions. Reg: use fins or buoy	M1–M2 (light in M3)
W3	Sculling / feel drills (water)	Propulsive feel; hand pathway; coordination under low speed	No special equipment (optional snorkel)	Soft wrists; continuous pressure; consistent hand pitch	4–6 × 15–25 m → 6–10 × 15–25 m → 4–6 × 15–25 m	Prog: add tempo or transition into swim. Reg: shorter distance	M1–M3