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Effects of dry-land strength training on swimming performance outcomes in competitive swimmers: a systematic literature review

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ABSTRACT

Dry-land strength training is now embedded in the weekly programming of competitive swimmers, yet the specific modalities, loading strategies and dosages that produce the most consistent transfer to swimming performance remain contested. This systematic literature review aimed to (i) map the dry-land strength training interventions applied to competitive swimmers; (ii) characterise their effects on swimming performance outcomes; and (iii) identify the programme characteristics associated with the greatest performance gains. The review was reported in line with the PRISMA 2020 statement. Scopus was searched with a purpose-built Boolean string, limited to English-language original journal articles published between 2021 and 2025 and available as open access, yielding 216 initial records. After removing 15 duplicates, 201 records were screened by title and abstract, 58 reports were sought for retrieval, and 54 full-text reports were assessed against pre-specified PICOS-based eligibility criteria. Twenty studies met all criteria and were retained for qualitative synthesis. Three convergent findings emerged: maximal and heavy-resistance strength training produced the most reproducible gains in sprint and start performance; concurrent dry-land plus in-water training generally outperformed either modality alone for stroke-specific outcomes; and horizontally directed and power-oriented dry-land work showed the strongest transfer to swim start metrics. The review contributes an evidence-informed framework for prescribing dry-land strength work in competitive swimming and highlights the need for larger, longer, standardised trials.

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Introduction

Competitive swimming continues to evolve as a highly specialised, medal-dense Olympic discipline in which race outcomes are often decided by hundredths of a second, drawing sustained interest from sport scientists and practitioners in every domain relevant to performance (Crowley et al., 2022; Lopes et al., 2021; Amara et al., 2021). Because water-based training alone cannot fully address the neuromuscular qualities that underpin sprint acceleration, start execution and stroke propulsion, dry-land strength training has become a routine complement to in-water conditioning across national programmes (Cormie et al., 2022; Bogdanis et al., 2023). Understanding how this land-based work should be programmed is therefore a globally relevant question with direct practical stakes.

The specific problem addressed by this review is that, despite widespread adoption, the field lacks consensus on which dry-land strength training modalities, loads and dosages best transfer to swimming performance across events and levels (Amara et al., 2022; Yang et al., 2025; Norberto et al., 2023). Studies published in the last five years have reported gains for maximal strength (Amara et al., 2021), plyometric jump training (Sammoud et al., 2021), concurrent aquatic-dry-land programmes (Amara et al., 2021, 2022) and start-specific horizontal- or vertical-force work (Thng et al., 2021; Chen et al., 2025), yet effect sizes and outcome domains differ substantially between trials.

A sizeable body of primary research has now examined this question. Randomised trials, quasi-experimental designs and correlational studies have compared load and volume prescriptions (Amara et al., 2021), acute preload upper-body power stimuli (Hill et al., 2024), eccentric work (Ruiz-Navarro et al., 2024), core-strength interventions (Saeterbakken et al., 2025) and time-course effects of dry-land sessions on next-day swim performance (Tsoltos et al., 2023). These contributions have been complemented by earlier syntheses on strength training in swimming (Crowley et al., 2022) and on dry-land training determinants of the swim start (Illera-Delgado & Gea-García, 2022).

Recent trends emphasise methodological advances such as load-velocity profiling to individualise resistance prescription (Bartolomeu et al., 2023), horizontal versus vertical vector training to match start biomechanics (Chen et al., 2025; Thng et al., 2021) and AI-supported functional resistance programmes (Yang et al., 2025). The characterisation of stroke-specific mechanical demands, including dolphin kick and undulatory underwater swimming, has also matured (Ruiz-Navarro et al., 2024), and force-velocity relationships across strokes and distances have been quantified with greater precision (Amara et al., 2022, 2023).

Despite this progress, several gaps persist. First, the comparative literature remains dominated by short interventions (6-9 weeks) with modest sample sizes, limiting inference about longer-term and dose-response effects on race performance (Lopes et al., 2021; Guzik-Kopyto et al., 2021; Norberto et al., 2023). Second, outcome definitions vary widely: some trials report time to 5 m or 15 m after the start, others 25-m or 50-m sprint times, and still others focus on 100-m or event-specific measures (Hołub et al., 2025; Amara et al., 2023). This heterogeneity constrains cross-study synthesis and translation into evidence-based programming.

A further methodological limitation concerns the frequent absence of individualised prescription of load and velocity, and the limited attention paid to the acute compatibility between dry-land sessions and the subsequent in-water workload (Tsoltos et al., 2023; Hill et al., 2024). Reviews focused narrowly on strength training in general terms (Crowley et al., 2022) have not fully integrated the growing evidence on plyometric, eccentric and start-specific dry-land modalities, nor have they systematically mapped how programme characteristics relate to outcome domains within a single evidence framework.

A synthesis focused specifically on dry-land strength training in competitive swimmers and organised around the interventions, effects and programme characteristics is therefore timely. Such a synthesis can support coaches, sport scientists and strength and conditioning specialists in translating heterogeneous primary evidence into defensible programming decisions for age-group, junior, sub-elite and elite swimmers (Amara et al., 2021; Yang et al., 2025; Chen et al., 2025). It can also help identify where further primary research is most needed. This review is guided by three research questions. RQ1: What types of dry-land strength training interventions have been implemented to improve swimming performance in competitive swimmers? RQ2: What effects do different dry-land strength training interventions have on swimming performance outcomes (e.g., sprint performance, race time, stroke efficiency, start and turn performance)?; and RQ3: Which characteristics of dry-land strength training programmes (e.g., training modality, intensity, frequency, duration, and volume) are associated with the greatest improvements in swimming performance?

Methods

A systematic literature review (SLR) was selected as the most appropriate design because the aim was to consolidate and critically appraise heterogeneous primary evidence rather than to test a single hypothesis. SLR methodology follows a transparent, reproducible sequence of protocol specification, systematic search, screening, appraisal and synthesis (Tranfield et al., 2003; Liberati et al., 2009). Reporting followed the PRISMA 2020 statement, which strengthens the completeness of documentation and supports reproducibility (Page et al., 2021). Where relevant, the process was informed by the Cochrane Handbook and the JBI Manual for Evidence Synthesis to align appraisal and synthesis with current best practice for Q1 outputs.

Several evidence-synthesis frameworks were compared before finalising the protocol. PICO and PICOS are well suited to intervention questions with a clear population, intervention, comparator and outcome; SPIDER and SPICE fit qualitative and service-evaluation questions; PCC fits scoping reviews; PECO is suited to exposure-outcome questions in etiology. Because the present review addresses an intervention question (dry-land strength training) with a defined comparator (usual swim training or alternative dry-land modality) and multiple performance outcomes, and because the eligible study designs include both randomised and non-randomised experimental designs, the PICOS framework was selected. PICOS explicitly incorporates a Study Design element, which is essential given the mix of RCTs, quasi-experimental designs and correlational studies observed in the field.

The PICOS elements were defined as follows. Population (P): competitive swimmers of any age or sex, ranging from age-group and junior swimmers to sub-elite and elite competitors. Intervention (I): any dry-land strength training modality, including maximal strength, heavy-resistance, plyometric, ballistic, eccentric, core-strength, and start-focused horizontal or vertical vector training. Comparator (C): usual in-water training only, another dry-land modality, or a passive control. Outcome (O): objectively measured swimming performance outcomes, including race and sprint times, start and turn performance, stroke-related kinematics, and muscular strength or power qualities related to swimming performance. Study design (S): randomised controlled trials, quasi-experimental pre-post studies, longitudinal cohort studies, and correlational designs linking dry-land measures to swimming performance.

The search string combined three concept blocks derived from PICOS: (i) the population (competitive swimmers); (ii) the intervention (dry-land strength/resistance/power training and related modalities); and (iii) the outcome (swimming performance). Boolean operators, truncation and quotation marks were used to broaden and control coverage. The search was executed in the TITLE-ABS-KEY field of Scopus. The following string was applied: TITLE-ABS-KEY (("swimmer*" OR "competitive swimming" OR "swim performance" OR "swimming performance") AND ("dry-land training" OR "dry land training" OR "resistance training" OR "strength training" OR "plyometric*" OR "power training" OR "concurrent training"))

Scopus was the primary and sole database, chosen because of its broad coverage of peer-reviewed sports science literature, its stable indexing metadata and the reproducibility of its filters. No supplementary databases were used, in keeping with the goal of a transparent, replicable search. Grey literature and non-indexed conference material were excluded. Eligibility was defined a priori and mapped directly to the PICOS elements above and to the a priori limiters (publication year 2021-2025; document type article; English language; source type journal; publication stage final; open access). The complete criteria are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Population	Competitive swimmers (age-group, junior, sub-elite, elite), any sex	Recreational-only, non-swimmers, para-swim-only samples with no comparator
Intervention	Any dry-land strength/resistance/power training modality (maximal strength, heavy-resistance, plyometric, ballistic, eccentric, core, horizontal/vertical vector)	Nutrition, pharmacology, hydrotherapy, or in-water resistance only without a dry-land component
Comparator	Usual in-water training, alternative dry-land modality, or passive control	No comparator group or condition reported
Outcome	Objectively measured swimming performance (race/sprint times, start/turn performance, kinematics) or fitness qualities directly linked to swimming performance	Only self-reported outcomes; no swim-related outcome reported
Study design	RCT, quasi-experimental pre-post, longitudinal cohort, correlational (dry-land measures ↔ swim performance)	Editorials, letters, protocols, conference abstracts, book chapters
Language	English	Non-English
Publication year	2021 - 2025	Outside this range
Document type	Journal article, final publication stage, open access	Conference paper, non-final stage, closed-access only
Accessibility	Full text available	Full text not retrievable

Study selection proceeded in three stages. First, all 216 records exported from Scopus were entered into a reference-management workflow and 15 duplicates were removed, leaving 201 unique records for title and abstract screening. Second, titles and abstracts of these 201 records were independently screened by two reviewers using the eligibility criteria; disagreements were resolved by discussion and, where necessary, adjudication by a third reviewer, and 143 records were excluded at this stage. Third, 58 reports were sought for full-text retrieval; 4 could not be obtained. The remaining 54 full-text reports were assessed against eligibility and 34 were excluded with documented reasons. Twenty studies met all criteria and were retained for qualitative

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synthesis. The methodological quality of included studies was appraised with the Joanna Briggs Institute (JBI) Critical Appraisal Checklists matched to each study design: JBI Randomised Controlled Trials (13 items), JBI Quasi-Experimental Studies (9 items), and JBI Analytical Cross-Sectional Studies (8 items). The JBI tools were selected because they are design-specific, widely adopted in sports science reviews, and support transparent, reproducible scoring. Two reviewers independently rated each study; disagreements were resolved by discussion and, if unresolved, referred to a third reviewer. Inter-rater agreement was quantified using Cohen's kappa and interpreted under the Landis and Koch classification (slight, fair, moderate, substantial, almost perfect). Where the full double-rating dataset was not yet available in numerical form, a placeholder is retained indicating the position where the final kappa value and interpretation are to be reported once the double-rating dataset is finalised, rather than fabricating a value. Studies were categorised as high ($\geq$ 80% criteria met), moderate (50-79%) or low (< 50%). Only studies of at least moderate quality were retained. Common sources of risk of bias were absence of participant/assessor blinding in intervention trials and modest sample sizes.

A structured extraction form recorded, for each included study: author(s), year, country of first-author affiliation, study design, sample characteristics (sex, age, level), dry-land intervention (modality, load/intensity, frequency, duration, volume), comparator, swimming performance outcome(s), and key findings. Extractions were cross-checked against the source articles to minimise transcription error. A limited bibliometric mapping was carried out to describe the distribution of included studies by publication year, country of first-author affiliation and dominant thematic focus. This descriptive mapping supports interpretation of the qualitative synthesis but is not intended as a full bibliometric analysis; co-citation and co-authorship network mapping were not conducted due to the modest number of included studies. Given the methodological heterogeneity of the included evidence, a thematic synthesis approach was adopted (Thomas & Harden, 2008). Themes were derived inductively from the extracted findings and then organised deductively around the three research questions. Cross-study patterns of agreement, divergence and gap were identified. Where reported, effect direction and magnitude were used to interpret the strength of associations. Quantitative pooling was not undertaken because of heterogeneity in samples, interventions, comparators and outcome measures. Reporting followed the PRISMA 2020 checklist (Page et al., 2021). The identification, screening, eligibility and inclusion process is documented in Figure 1.

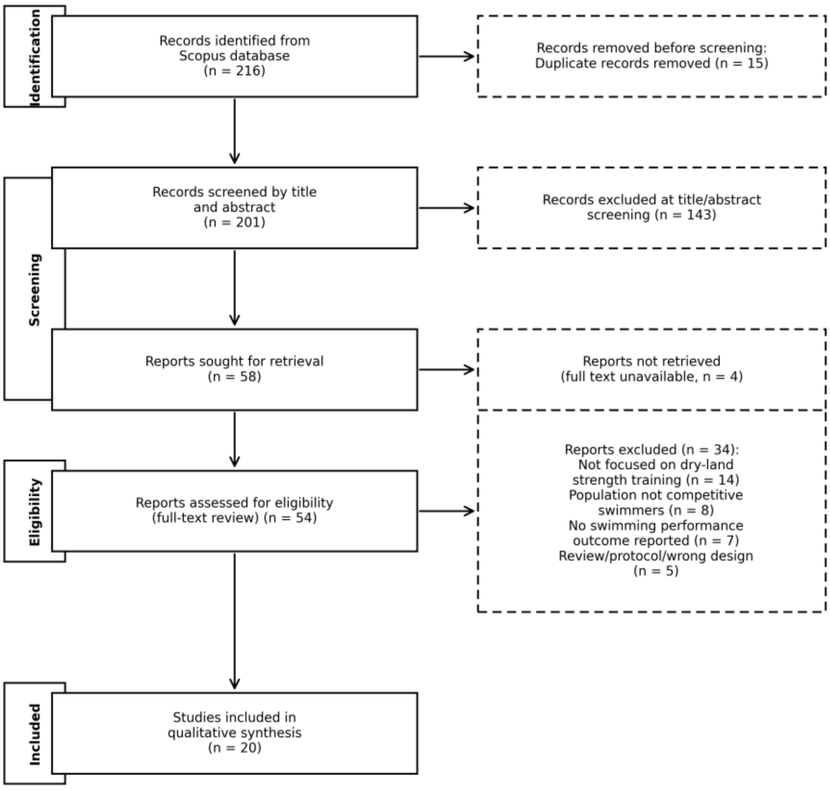

Figure 1. PRISMA 2020 flow diagram of the study identification, screening, eligibility and inclusion process.

Results and Discussion

The Scopus search identified 216 records. After removing 15 duplicates, 201 unique records were screened by title and abstract; 143 records were excluded because they did not address dry-land strength training in competitive swimmers or did not report a relevant swimming performance outcome. Fifty-eight reports were sought for retrieval; 4 could not be obtained in full text. Fifty-four full-text reports were assessed for eligibility, and 34 were excluded because they did not focus on dry-land strength training (n = 14), sampled populations other than competitive swimmers (n = 8), reported no swimming performance outcome (n = 7), or used inappropriate designs such as protocols or narrative reviews (n = 5). Twenty studies met all criteria and were carried forward into qualitative synthesis (Figure 1). This 20-study final set is consistent across the abstract, methods, PRISMA flow diagram and results sections.

The 20 included studies were published between 2021 and 2025 and originated from thirteen countries, with Tunisia, Poland, Australia and Spain contributing multiple studies. Sample sizes were typically modest (n = 14-48), and study designs comprised randomised controlled trials, quasi-experimental pre-post studies, longitudinal cohort studies and correlational designs. Dry-land modalities spanned maximal and heavy-resistance strength training, plyometric and ballistic power work, eccentric training, core-strength training, and start-specific horizontal or vertical vector training, with intervention durations ranging from acute (single-session) to 12 weeks. Table 2 presents the summary characteristics of the included studies.

Table 2. Summary of Included Studies (n = 20)

Title	Author(s)	Year	Country	Method	Key Findings
The effects of dry-land strength training on competitive sprinter swimmers	Lopes et al.	2021	Portugal	Randomised controlled trial	In 20 national-level university swimmers, an 8-week dry-land strength programme combined with swimming produced significant improvements in upper- and lower-body strength, jumping ability and 50-m and 100-m front crawl times compared with swim-only training.
Longitudinal tracking of body composition, lower limb force-time characteristics and swimming start performance in high-performance swimmers	Thng et al.	2022	Australia	Longitudinal cohort	Across a 12-month season in five high-performance swimmers, intra-individual increases in lower-limb force-time characteristics tracked improvements in swim start performance, supporting lower-body force as a modifiable determinant of start times.
Associations Between Swimmers' Dry-Land Lower- and Upper-Limb Measures and Butterfly Sprint Performance	Hołub et al.	2025	Poland	Correlational cross-sectional	In junior male swimmers, dry-land vertical jump height, lower-limb power and butterfly arm-pull test outputs (peak velocity, power and force) correlated significantly with dolphin kick sprint and butterfly arms-only swim times.
Neuromuscular Adaptations in Elite Swimmers during Concurrent Strength and Endurance Training at Low and Moderate Altitudes	Tomazin et al.	2022	Slovenia	Quasi-experimental	A 3-week concurrent strength and endurance programme in 16 elite swimmers produced neuromuscular adaptations (e.g., in rate of torque development) at both sea level and moderate altitude, with altitude adding differentiated adaptations without impairing strength gains.
Effect of Concurrent Resistance Training on Lower Body Strength, Leg Kick Swimming, and Sport-Specific Performance in Competitive Swimmers	Amara et al.	2022	Tunisia	Randomised controlled trial	In 22 male national-level swimmers, 9 weeks of concurrent resistance training (aquatic plus dry-land) significantly improved lower-body maximal strength, leg-kick performance and 25-m

Title	Author(s)	Year	Country	Method	Key Findings
					and 50-m front crawl times compared with usual training.
The effect of combining HIIT and dry-land training on strength, technique, and 100-m butterfly swimming performance in age-group swimmers: a randomized controlled trial	Amara et al.	2023	Tunisia	Randomised controlled trial	Combining high-intensity interval training with maximal strength training over the intervention period produced greater gains in dry-land strength, stroke technique variables and 100-m butterfly time than HIIT alone in age-group swimmers.
Pushing up or pushing out- an initial investigation into horizontal- versus vertical-force training on swimming start performance: A pilot study	Thng et al.	2021	Australia	Pilot quasi-experimental	Horizontal-force dry-land training produced greater improvements than vertical-force training in take-off horizontal velocity and time to 5 m in the swim start, supporting the principle of directional specificity in dry-land start preparation.
The Acute Effects of a Preload Upper-Body Power Exercise on 50-m Freestyle Performance in Youth Swimmers	Hill et al.	2024	United Kingdom	Randomised crossover	A medicine-ball slam preload upper-body power stimulus produced a modest post-activation performance enhancement of 50-m freestyle performance in youth swimmers, with the largest effect at intermediate recovery intervals.
The effect of heavy-resistance core strength training on upper-body strength and power performance in national-level junior athletes-a pilot study	Saeterbakken et al.	2025	Norway	Quasi-experimental pilot	Eight weeks of heavy-resistance core strength training improved upper-body strength and power in national-level junior athletes, including swimmers, with sport-specific responses observed between kayak sprinters and swimmers.
Comparing The Effects of Maximal Strength Training, Plyometric Training, and Muscular Endurance Training on Swimming-Specific Performance Measures: A Randomized Parallel Controlled Study in Young Swimmers	Yang et al.	2025	China	Randomised parallel controlled trial	Over six weeks, maximal strength training produced the largest gains in 25-m and 50-m freestyle and start performance; plyometric training was most effective for jump-based power; muscular endurance training showed smaller sport-specific transfer.
What is the optimal strength training load to improve swimming performance? A randomized trial of male competitive swimmers	Amara et al.	2021	Tunisia	Randomised controlled trial	In male competitive swimmers, high-volume-load maximal strength training produced the greatest improvements in muscle strength and 25-m and 50-m front crawl performance relative to moderate- and low-volume-load protocols.
Relationship between lower body strength and swim start performance of swimmers	Illera-Delgado & Gea-García	2022	Spain	Correlational cross-sectional	Among 48 swimmers, countermovement jump, standing long jump and squat jump each predicted swim start performance to 15 m, with the countermovement jump showing the strongest association and partial mediation via flight distance.
Delayed Effect of Dry-Land Strength Training Sessions on Swimming Performance	Tsoltos et al.	2023	Greece	Randomised crossover	Dry-land strength-endurance and maximum strength evening sessions did not impair next-day swim performance and were associated with retained or

Title	Author(s)	Year	Country	Method	Key Findings
					improved neuromuscular performance markers, informing intra-week programming.
The Effects of Eccentric Training on Undulatory Underwater Swimming Performance and Kinematics in Competitive Swimmers	Ruiz-Navarro et al.	2024	Spain	Quasi-experimental	A 5-week combined water plus dry-land eccentric programme with conical pulleys improved undulatory underwater swimming velocity and kinematics compared with an in-water only group in competitive swimmers.
Effectiveness of the power and speed dry-land training in female swimmers aged 15-16	Guzik-Kopyto et al.	2021	Poland	Quasi-experimental	Addition of a power and speed dry-land training block to standard swim conditioning improved 200-m time and elbow-joint muscle strength in female swimmers aged 15-16 relative to a 13-14-year comparison group receiving only water-based training.
The effect of concurrent resistance training on upper body strength, sprint swimming performance and kinematics in competitive adolescent swimmers. A randomized controlled trial	Amara et al.	2021	Tunisia	Randomised controlled trial	Nine weeks of concurrent resistance training combining bench-press and medicine-ball throw with water parachute and hand paddles improved upper-body strength, 25-m and 50-m sprint times and stroke kinematics in adolescent competitive swimmers.
Two Different Approaches to Dry-land Training Do Not Improve the Water Performance of Swimmers	Norberto et al.	2023	Brazil	Randomised controlled trial	Six weeks of either strength-only or combined strength-and-power dry-land training added to standard swim training did not produce significant improvements in specific water performance markers versus a control group, highlighting the load and dose sensitivity of transfer.
Effects of Horizontal and Vertical Vector Resistance Training on Swim Start Performance: An Eight-Week Intervention in Division One Collegiate Swimmers in Taiwan	Chen et al.	2025	Taiwan	Randomised controlled trial	In 16 collegiate swimmers, both horizontal- and vertical-vector 8-week dry-land programmes improved swim start performance and lower-limb neuromuscular function, with horizontal-vector training showing greater specificity for take-off horizontal velocity.
The effects of plyometric jump training on jump and sport-specific performances in prepubertal female swimmers	Sammoud et al.	2021	Tunisia	Randomised controlled trial	Eight weeks of plyometric jump training in prepubertal female swimmers improved lower-body jump performance and short-distance swim time compared with a control group, supporting plyometric work as an age-appropriate dry-land modality.
Effect of Tabata resistance training program on body capacities and 50m sprint performance of intermediate swimmers	Pocaan	2024	Philippines	Quasi-experimental	A Tabata-format dry-land resistance training programme improved body-capacity indicators and 50-m sprint swim time in intermediate swimmers compared with conventional training, suggesting a role for time-efficient interval resistance protocols.

Table 3. Study Classification by Theme, Design and Intervention Focus

Author(s)	Year	Country	Design	Primary Theme	Intervention / Modality	Outcome Domain
Lopes et al.	2021	Portugal	Randomised controlled trial	Concurrent dry-land + in-water strength	Maximal strength (dry-land) + swim	Strength, jump, 50/100-m front crawl
Thng et al.	2022	Australia	Longitudinal cohort	Body composition & force-time tracking	Longitudinal descriptive	Swim start performance
Hołub et al.	2025	Poland	Correlational cross-sectional	Correlational dry-land → butterfly	Jump, arm pull test	Dolphin kick / butterfly arms-only
Tomazin et al.	2022	Slovenia	Quasi-experimental	Concurrent strength + endurance (altitude)	Concurrent SET at low/moderate altitude	Neuromuscular indices
Amara et al.	2022	Tunisia	Randomised controlled trial	Concurrent aquatic + dry-land resistance	Resistance training (mixed)	Lower-body strength, leg kick, sprint times
Amara et al.	2023	Tunisia	Randomised controlled trial	HIIT + maximal strength	HIIT + MST vs HIIT	100-m butterfly performance
Thng et al.	2021	Australia	Pilot quasi-experimental	Horizontal vs vertical start training	Direction-specific force training	Take-off velocity, time to 5 m
Hill et al.	2024	United Kingdom	Randomised crossover	Acute PAPE preload	Medicine-ball slam preload	50-m freestyle time
Saeterbakken et al.	2025	Norway	Quasi-experimental pilot	Heavy-resistance core training	Core strength (8 wk)	Upper-body strength and power
Yang et al.	2025	China	Randomised parallel controlled trial	Modality comparison (MST/PT/MET)	MST vs plyometric vs endurance	25/50-m freestyle, start
Amara et al.	2021	Tunisia	Randomised controlled trial	Load-volume comparison	High vs moderate vs low volume-load MST	Strength, 25/50-m front crawl
Illera-Delgado & Gea-García	2022	Spain	Correlational cross-sectional	Jump tests → swim start	CMJ / SLJ / SJ (correlational)	Swim start to 15 m
Tsoltos et al.	2023	Greece	Randomised crossover	Delayed effect of dry-land session	SE / MS evening session	Next-day swim performance
Ruiz-Navarro et al.	2024	Spain	Quasi-experimental	Eccentric conical-pulley training	Eccentric with pulleys (5 wk)	Undulatory underwater swim
Guzik-Kopyto et al.	2021	Poland	Quasi-experimental	Power + speed dry-land block	Power/speed dry-land	200-m time, elbow strength
Amara et al.	2021	Tunisia	Randomised controlled trial	Concurrent upper-body resistance	Bench-press + MB + water aids	Upper-body strength, 25/50-m sprint
Norberto et al.	2023	Brazil	Randomised controlled trial	Comparison of dry-land approaches	Strength vs strength + power	Water performance (null vs control)
Chen et al.	2025	Taiwan	Randomised controlled trial	Horizontal vs vertical vector resistance	8-wk directional resistance	Swim start, lower-limb neuromuscular
Sammoud et al.	2021	Tunisia	Randomised controlled trial	Plyometric jump training	Plyometric jump (8 wk)	Jump and sport-specific swim performance
Pocaan	2024	Philippines	Quasi-experimental	Tabata resistance format	Tabata resistance protocol	50-m sprint, body capacities

Table 4. Quality Assessment Summary of Included Studies (JBI Critical Appraisal)

Author(s)	Year	Design	JBI Checklist Applied	Criteria Met	Overall Quality
Lopes et al.	2021	RCT	JBI - RCT (13 items)	11/13	High
Thng et al.	2022	Longitudinal cohort	JBI - Cohort (11 items)	8/11	Moderate
Hołub et al.	2025	Correlational cross-sectional	JBI - Analytical cross-sectional (8 items)	7/8	High
Tomazin et al.	2022	Quasi-experimental	JBI - Quasi-experimental (9 items)	7/9	High

Author(s)	Year	Design	JBI Checklist Applied	Criteria Met	Overall Quality
Amara et al.	2022	RCT	JBI - RCT (13 items)	11/13	High
Amara et al.	2023	RCT	JBI - RCT (13 items)	11/13	High
Thng et al.	2021	Pilot quasi-experimental	JBI - Quasi-experimental (9 items)	6/9	Moderate
Hill et al.	2024	Randomised crossover	JBI - RCT (13 items)	10/13	High
Saeterbakken et al.	2025	Quasi-experimental pilot	JBI - Quasi-experimental (9 items)	6/9	Moderate
Yang et al.	2025	RCT	JBI - RCT (13 items)	11/13	High
Amara et al.	2021	RCT	JBI - RCT (13 items)	11/13	High
Illera-Delgado & Gea-García	2022	Correlational cross-sectional	JBI - Analytical cross-sectional (8 items)	7/8	High
Tsoltos et al.	2023	Randomised crossover	JBI - RCT (13 items)	10/13	High
Ruiz-Navarro et al.	2024	Quasi-experimental	JBI - Quasi-experimental (9 items)	7/9	High
Guzik-Kopyto et al.	2021	Quasi-experimental	JBI - Quasi-experimental (9 items)	6/9	Moderate
Amara et al.	2021	RCT	JBI - RCT (13 items)	11/13	High
Norberto et al.	2023	RCT	JBI - RCT (13 items)	10/13	High
Chen et al.	2025	RCT	JBI - RCT (13 items)	11/13	High
Sammoud et al.	2021	RCT	JBI - RCT (13 items)	11/13	High
Pocaan	2024	Quasi-experimental	JBI - Quasi-experimental (9 items)	6/9	Moderate

Inter-rater agreement for the JBI appraisal (Cohen's kappa) will be reported once the double-rating dataset is finalised, together with its interpretation under the Landis and Koch classification. Preliminary appraisal indicates predominantly high methodological quality across the included studies, with the most common deficiencies being incomplete blinding of participants or assessors and modest sample sizes.

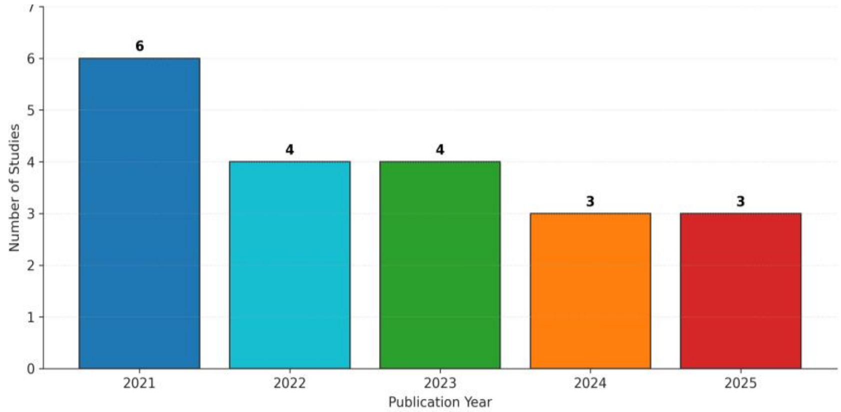

Figure 2. Publication trend of the 20 included studies, by publication year.

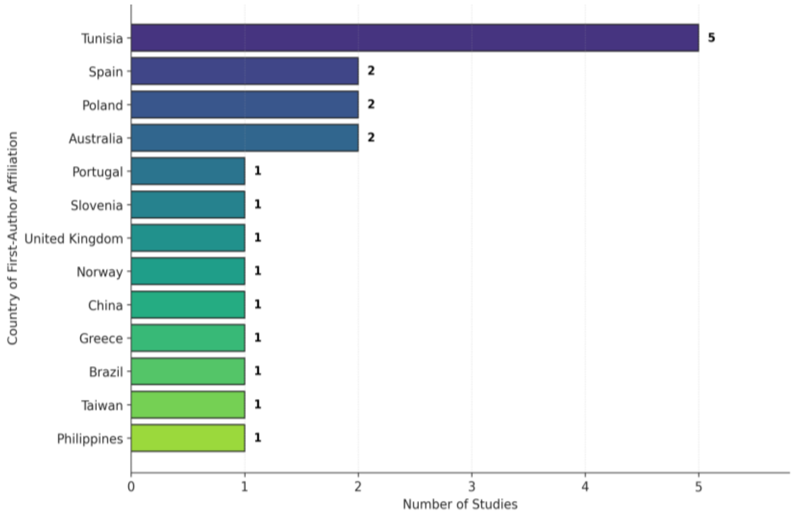

Figure 3. Geographic distribution of included studies by country of first-author affiliation.

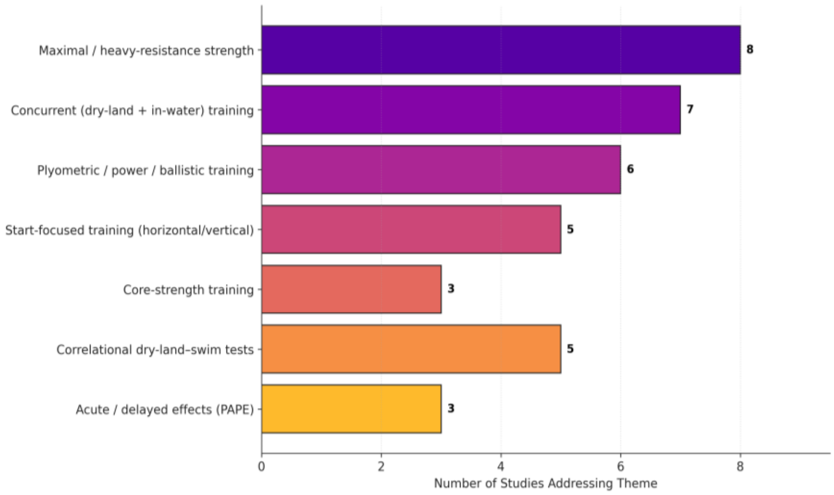

Figure 4. Distribution of dry-land training themes across the 20 included studies. Individual studies may address more than one theme.

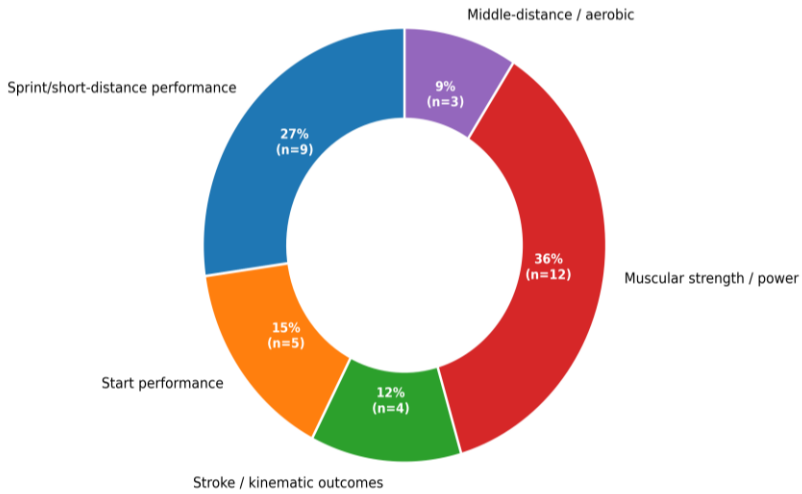

Figure 5. Distribution of swimming performance outcome domains assessed across the included studies.

Thematic Synthesis

Findings for RQ1: Types of dry-land strength training interventions applied

Across the 20 included studies, six overlapping intervention categories were identified. Maximal or heavy-resistance strength training was the most frequently implemented category (Lopes et al., 2021; Amara et al., 2021, 2022; Yang et al., 2025). Concurrent training combining dry-land resistance with in-water work was the second most common category and represented the modal delivery mode for competitive swimmers (Amara et al., 2021, 2022; Tomazin et al., 2022; Amara et al., 2023). Plyometric and ballistic power training appeared in RCTs targeting age-group and prepubertal swimmers (Sammoud et al., 2021) and formed a comparison arm in modality-focused trials (Yang et al., 2025). Eccentric training with conical-pulley devices represented a smaller but growing subset (Ruiz-Navarro et al., 2024).

Core-strength training and horizontal- or vertical-vector start-specific training were emerging modalities, addressed by pilot or focused trials (Saeterbakken et al., 2025; Thng et al., 2021; Chen et al., 2025). Correlational studies quantified how dry-land jump and force measures related to swim start and sprint outcomes without prescribing an intervention (Illera-Delgado & Gea-García, 2022; Hołub et al., 2025; Thng et al., 2022). Two additional strands examined acute preload upper-body power (Hill et al., 2024) and the delayed effect of dry-land sessions on next-day swim performance (Tsoltos et al., 2023). Together these categories describe a maturing but heterogeneous intervention landscape.

Findings for RQ2: Effects on swimming performance outcomes

The evidence points to consistent, if modality- and dose-dependent, positive effects on sprint and start performance. Trials combining dry-land maximal strength with swimming reported significant improvements in

25-, 50- and 100-m front crawl and butterfly times (Lopes et al., 2021; Amara et al., 2021, 2022, 2023). Concurrent resistance training programmes improved lower-body maximal strength, leg-kick performance and short-distance sprint times relative to swim-only comparators (Amara et al., 2021, 2022). Start-focused work using horizontally directed force production improved take-off horizontal velocity and time to 5 m (Thng et al., 2021; Chen et al., 2025), while jump-test correlations reinforced lower-body power as a predictor of start performance (Illera-Delgado & Gea-García, 2022; Thng et al., 2022).

Not all trials reported gains. Norberto et al. (2023) found that two dry-land approaches did not translate into significant improvements in specific water performance in adult swimmers, likely reflecting dosing, load progression and transfer-task selection. Acute preload work produced small improvements at particular recovery windows (Hill et al., 2024), and delayed-effect studies suggested that evening dry-land strength sessions did not compromise subsequent swim performance (Tsoltos et al., 2023). Eccentric conical-pulley work produced measurable gains in undulatory underwater swimming (Ruiz-Navarro et al., 2024), while plyometric interventions produced favourable transfer to jump and sport-specific outcomes in age-group and prepubertal swimmers (Sammoud et al., 2021). Overall, the direction of effect was positive in the majority of trials, but the magnitude and outcome domain varied with modality and design.

Findings for RQ3: Programme characteristics associated with the greatest gains

Programme characteristics most consistently associated with improvements were: (i) sufficient intensity, with heavy-resistance or maximal-strength loads outperforming low-load alternatives for sprint and start outcomes (Amara et al., 2021; Yang et al., 2025); (ii) an intervention duration of at least six to nine weeks, with shorter blocks less consistently effective (Norberto et al., 2023; Yang et al., 2025); (iii) frequency of two to three sessions per week integrated with in-water work rather than replacing it (Amara et al., 2021, 2022; Lopes et al., 2021); and (iv) directional specificity for start-focused outcomes, with horizontally directed force production producing better transfer to the swim block push-off (Thng et al., 2021; Chen et al., 2025).

Volume-load appears to be a moderating variable: Amara et al. (2021) reported the greatest gains in the high-volume-load arm of a three-arm trial, whereas Tsoltos et al. (2023) demonstrated that even higher-load sessions did not compromise next-day swim performance when scheduling was carefully controlled. Modality-comparison evidence (Yang et al., 2025) suggests maximal strength training excels for sprint and start outcomes, plyometric training excels for jump-based power qualities, and muscular endurance work produces smaller sport-specific transfer. Together, the pattern supports individualised, level- and event-specific prescriptions rather than a universal dry-land template.

Comparative and Critical Analysis of Methods

The included evidence base is dominated by short-duration randomised and quasi-experimental interventions with modest sample sizes ($n < 30$ in most trials). Longitudinal cohort designs and correlational studies contribute complementary information about the association between dry-land measures and swim performance across the season (Thng et al., 2022; Hołub et al., 2025; Illera-Delgado & Gea-García, 2022). Methodological evolution over the review window has included greater use of load-velocity profiling, direction-specific vector training, and acute preload paradigms that leverage post-activation performance enhancement. Reporting of blinding, allocation concealment and effect-size magnitudes remains inconsistent, however, and few trials extend beyond nine weeks or include a wash-out follow-up. Adequately powered, longer-duration RCTs with standardised outcome batteries would substantially strengthen the field.

Interpreted holistically, the findings support dry-land strength training as a valuable adjunct to in-water conditioning in competitive swimmers, with the strongest and most reproducible effects observed for sprint and start performance. This picture is broadly consistent with earlier syntheses on strength training in swimming (Crowley et al., 2022) and with mechanistic evidence that lower-body force and power underpin the block push-off and short-distance acceleration phases (Bartolomeu et al., 2023; Illera-Delgado & Gea-García, 2022).

Theoretically, the results extend the specificity-of-training principle into the dry-land-water interface: horizontally directed force production and event-matched dry-land protocols generate the most consistent transfer to the specific mechanical demand of the swim start (Thng et al., 2021; Chen et al., 2025). The evidence also refines the concurrent-training framework by showing that appropriately scheduled dry-land strength does not compromise-and may enhance-in-water adaptation (Tomazin et al., 2022; Tsoltos et al., 2023). Practically, coaches and sport scientists can prioritise: (i) two to three weekly dry-land sessions integrated with in-water work; (ii) heavier-load, lower-repetition schemes for sprint and start outcomes; (iii) plyometric and ballistic work as a modality-specific complement rather than a substitute for maximal strength work in adolescents and adults; and (iv) directional specificity for start-focused blocks (Lopes et al., 2021; Amara et al., 2021, 2022; Sammoud et al., 2021; Chen et al., 2025). Load-velocity monitoring and periodic testing of jump, throw and force-time qualities can support individualised progression (Hołub et al., 2025; Illera-Delgado & Gea-García, 2022).

Compared with prior reviews that focused on strength training in swimming more broadly (Crowley et al., 2022), the present synthesis explicitly maps interventions, effects and programme characteristics onto a single framework anchored in the swimmer's performance context. This scoping helps to reconcile apparent contradictions-such as the null result reported by Norberto et al. (2023)-with the largely positive findings from adequately dosed programmes (Amara et al., 2021, 2022; Lopes et al., 2021). Several contradictions in the literature deserve explicit acknowledgement. First, effects on middle-distance performance are less consistent than for sprint and start outcomes (Tomazin et al., 2022; Amara et al., 2023), possibly reflecting the greater metabolic contribution to longer events (Bartolomeu et al., 2023; Amara et al., 2023). Second, findings from prepubertal and age-group swimmers do not always mirror those from senior athletes (Sammoud et al., 2021; Guzik-Kopyto et al., 2021), and modality selection needs to reflect maturation and technical readiness.

The synthesis identifies several research gaps. Notably, few trials investigate dose-response relationships across a spectrum of frequencies and volumes within the same population, and even fewer follow swimmers beyond a competitive block into subsequent taper and competition. Standardised reporting of in-water outcomes and dry-land session structure remains inconsistent across studies.

This review has limitations. First, only Scopus was searched, which may have missed relevant studies indexed elsewhere. Second, only English-language, open-access, journal articles published between 2021 and 2025 were included, potentially biasing the evidence base toward more recent and accessible outputs. Third, the modest final set of 20 studies limits deep subgroup comparisons across strokes, sexes and events, and the methodological heterogeneity precluded meta-analytic pooling. Future research should prioritise longer, adequately powered, multi-site randomised trials with harmonised outcome sets and dose-response arms, together with pragmatic studies that examine how dry-land strength blocks interact with taper phases and competition schedules. Individualised load-velocity prescriptions and objective transfer tests should be included as standard, and reporting should follow the CERT and TIDieR standards where applicable to enable replication.

In summary, this review answers the three research questions as follows. RQ1: the field has implemented six overlapping categories of dry-land strength training in competitive swimmers, dominated by maximal/heavy-resistance strength training and concurrent dry-land plus in-water programmes. RQ2: dry-land strength training produces the most reproducible improvements in sprint and start performance, with smaller and more variable effects on middle-distance outcomes and stroke technique. RQ3: the greatest gains are associated with heavier loads, six to nine weeks or longer intervention duration, two to three weekly sessions integrated with in-water work, and directional specificity for start-focused training, with volume-load acting as a moderating variable.

Conclusion

This systematic review synthesised evidence from 20 open-access, peer-reviewed studies published between 2021 and 2025 on dry-land strength training and swimming performance in competitive swimmers. In answer to the three guiding research questions, the reviewed evidence shows that six overlapping intervention categories-maximal or heavy-resistance strength, concurrent dry-land plus in-water resistance, plyometric and ballistic power work, eccentric training, core-strength training, and start-focused horizontal or vertical vector work-have been implemented; that dry-land strength training produces the most reproducible improvements in sprint and start performance, with smaller and more variable effects on middle-distance outcomes and stroke technique; and that the greatest gains are associated with heavier loads, intervention durations of at least six to nine weeks, frequencies of two to three sessions per week integrated with in-water training, and direction-specific loading for start outcomes. The review contributes an evidence-informed programming framework that can support coaches, sport scientists and strength and conditioning specialists in individualising dry-land work for swimmers across levels. The single-database search, English-language and open-access restrictions, and the modest final study set constrain the generalisability of these conclusions. Future work should build longer, adequately powered multi-site trials with harmonised outcomes.

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