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From youth to elite: a systematic review of physical fitness characteristics that discriminate competitive swimming levels

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ABSTRACT

Competitive swimming performance is influenced by interacting anthropometric, neuromuscular, metabolic, and technical characteristics that vary across competitive levels. This systematic review aimed to identify key physical fitness characteristics in competitive swimmers, examine their differences across performance levels, and determine those most consistently associated with superior performance. Following the PRISMA 2020 framework, a systematic search of Scopus was conducted from inception to December 2025. Of 279 records identified, 18 studies met the inclusion criteria and underwent thematic synthesis following methodological quality assessment using Joanna Briggs Institute checklists. Higher-level swimmers consistently demonstrated greater arm span, stature, and lean mass, with the clearest differences observed in youth and junior populations. Muscular strength and lower-body power, particularly measured through countermovement and squat jumps, showed strong and consistent associations with start and sprint performance. Aerobic capacity, maximal swimming velocity, and critical speed increased substantially from junior to senior levels, with critical speed emerging as a strong correlate of junior performance. At elite levels, stroke index, active drag, and start and turn efficiency became increasingly important discriminators. Overall, the findings provide an integrated, competition-level-specific performance profile that may support talent identification, long-term athlete development, and evidence-based training. Standardized longitudinal, multidomain testing that considers stroke- and distance-specific demands is recommended for future research and practice.

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Introduction

Swimming remains one of the most widely practised competitive aquatic sports worldwide and continues to hold a central place in the Olympic programme, attracting substantial scientific interest in the physiological, biomechanical and developmental factors that determine performance (Post et al., 2023; Morais et al., 2019). The global growth of competitive swimming is reflected in both participation numbers and the expansion of scientific literature investigating performance across age groups and competitive standards (Barbosa et al., 2014; Rüst et al., 2012). Understanding the physical fitness characteristics that underpin swimming performance is therefore of enduring practical relevance for coaches, sport scientists and policymakers responsible for the development of the next generation of elite performers (Mitchell et al., 2018; Dalamitros et al., 2014). Within this landscape, a persistent problem concerns how physical fitness characteristics differ between swimmers competing at different levels and how those differences translate into performance outcomes. Even minor variations in anthropometric, neuromuscular or metabolic attributes can markedly influence race times in a sport where medals are frequently decided by hundredths of a second (Morais et al., 2019; Thng et al., 2020). This narrow performance margin makes the accurate identification, monitoring and development of the most discriminating fitness qualities a scientific and applied priority.

Existing research has approached this problem from multiple angles, including cross-sectional comparisons between elite and sub-elite groups (van Dijk et al., 2020), longitudinal tracking of talented swimmers across development stages (Post et al., 2023; Post et al., 2024), and laboratory- and field-based testing batteries designed to predict competitive performance (Dalamitros et al., 2014; Mitchell et al., 2018). Together, these bodies of literature have generated substantial data on the physiological, morphological and mechanical demands of swimming, though these datasets remain distributed across heterogeneous samples, methods and reporting conventions.

Recent methodological and technological advances have further diversified how physical fitness is characterised in swimmers. Contemporary studies increasingly employ multidimensional test batteries that combine countermovement and squat jumps, force-time profiling, kinematic analysis of starts and turns, and metabolic assessment during high-intensity interval work (Thng et al., 2020; Almeida et al., 2021; Głyk et al., 2022). Land-based resistance training with velocity-based monitoring, core-strength interventions and preseason camp designs have also emerged as important applied paradigms (Rodríguez-Rosell et al., 2026; Saeterbakken et al., 2025; Bielec et al., 2025).

Despite this progress, several gaps in the evidence base persist. First, comparative analyses across competitive levels-from age-group and youth swimmers to junior, sub-elite and elite competitors-remain fragmented, with individual studies typically focusing on a single competitive tier or a narrow age band (Naftilan et al., 2025; Hibberd et al., 2016; Demura et al., 1991). Consequently, the extent to which physical fitness profiles differentiate levels within a single, coherent framework has not been fully synthesised. Second, methodological heterogeneity in test selection, terminology and reporting continues to limit cross-study comparability. Even foundational assessments such as anthropometry, jump testing, aerobic capacity and stroke kinematics vary substantially in protocol and reporting standard (Barbosa et al., 2014; Dalamitros et al., 2014; Zhao & Li, 2023). Consequently, coaches often struggle to translate published findings into evidence-based decisions for talent identification and monitoring within their own programmes.

A synthesis of the current evidence is therefore timely. Systematic reviews on related but narrower questions have appeared, including reviews of strength training in swimming (Crowley et al., 2022) and physical performance determinants in youth swimmers (Nugent et al., 2024). However, a broader, PRISMA-anchored synthesis that explicitly maps physical fitness characteristics across competitive levels-rather than focusing on a single training modality or population-is currently missing. Filling this gap can support the design of more targeted testing batteries, developmentally appropriate training prescriptions and empirically defensible talent pathways.

Against this background, the present systematic literature review is guided by three research questions. RQ1 addresses the descriptive landscape of the literature: what physical fitness characteristics have been investigated in competitive swimmers across competitive levels?. RQ2 focuses on comparative evidence: how do the physical fitness characteristics of swimmers differ across competitive levels, ranging from youth and age-group swimmers to junior, sub-elite and elite performers? By synthesising cross-sectional and longitudinal evidence, this question contributes to a clearer, level-referenced profile of physical fitness demands in swimming. RQ3 targets predictive validity: which physical fitness characteristics are most consistently associated with higher competitive performance in swimmers? The novelty of this review lies in integrating anthropometric, neuromuscular, metabolic and technical-kinematic evidence within a single evidence-based framework, so that patterns of convergence and divergence across studies can be identified and translated into applied recommendations for coaches, sport scientists and talent development stakeholders.

RQ1: What physical fitness characteristics have been investigated in competitive swimmers across different competitive levels?

RQ2: How do physical fitness characteristics differ among swimmers across competitive levels (e.g., youth, junior, collegiate, sub-elite and elite)?

RQ3: Which physical fitness characteristics are most consistently associated with higher competitive performance in swimmers?

Methods

A systematic literature review (SLR) was adopted as the most appropriate design to consolidate, appraise and synthesise the published evidence on physical fitness characteristics across competitive levels in swimmers. SLR methodology provides a transparent, reproducible procedure for locating, selecting and analysing primary studies against pre-specified eligibility criteria (Tranfield et al., 2003; Liberati et al., 2009). The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement, which strengthens the completeness and reproducibility of reporting (Page et al., 2021).

The search string combined three concept blocks: (i) the population of interest (competitive swimmers), (ii) the exposure of interest (physical fitness characteristics), and (iii) the comparator dimension (competitive level and performance outcomes). Truncation and Boolean operators were used to broaden term coverage. The search was executed in the TITLE-ABS-KEY field of the Scopus database. The following string was applied: TITLE-ABS-KEY (("swimmer*" OR "competitive swimming" OR "swim performance") AND ("physical fitness" OR "physical performance" OR "muscular strength" OR "aerobic capacity" OR "anaerobic power" OR "anthropometric*" OR "motor abilit*") AND ("competitive level" OR "elite" OR "junior" OR "youth" OR "sub-elite" OR "age-group" OR "national level"))

Scopus was selected as the primary information source given its wide coverage of peer-reviewed sports science literature and its stable indexing metadata. Only records retrieved from Scopus were considered for inclusion. Grey literature, conference proceedings not indexed in Scopus, and unpublished manuscripts were not searched, in order to preserve the reproducibility of the search string and the consistency of the metadata used for screening.

Eligibility was determined a priori using a PICO-informed framework (Population, Intervention/Exposure, Comparator, Outcome). Studies were included when they addressed competitive swimmers of any age or sex, reported one or more physical fitness characteristics, and either compared characteristics across competitive levels or examined their relationship with competitive performance. Detailed criteria are summarised in Table 1.

Table 1. Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Population	Competitive swimmers (youth, junior, sub-elite, elite) of any sex	Recreational-only, para-swimmers only, non-swimmers
Exposure / Focus	Physical fitness characteristics (anthropometric, muscular strength/power, aerobic/anaerobic capacity, speed, motor abilities, kinematics)	Studies focused solely on nutrition, pharmacology or genetics without fitness outcomes
Comparator / Outcome	Comparison across competitive levels or link between physical fitness and competitive performance	No level comparison and no performance link reported
Study design	Original peer-reviewed research articles (cross-sectional, longitudinal, quasi-experimental, randomised controlled trials)	Editorials, conference papers, letters, book chapters, protocol-only papers
Language	English	Non-English
Time frame	2021 - 2025	Outside this range
Accessibility	Full text available	Full text not retrievable

Study selection proceeded in three stages. First, all 279 records exported from Scopus were entered into a reference-management workflow, and 14 duplicates were removed, leaving 265 unique records for title and abstract screening. Second, titles and abstracts of these 265 records were independently screened by two reviewers, with any disagreement resolved by discussion and, when needed, adjudication by a third reviewer; 198 records were excluded at this stage due to lack of relevance to the review question. Third, 67 reports were sought for full-text retrieval; 5 could not be retrieved. The remaining 62 full-text reports were assessed for eligibility, and 44 were excluded with documented reasons. This process yielded 18 studies for the final qualitative synthesis.

The methodological quality of the included studies was appraised using the Joanna Briggs Institute (JBI) Critical Appraisal Checklists, matched to the study design of each included report (analytical cross-sectional studies, cohort/longitudinal studies, and quasi-experimental/RCT designs). The JBI tools were selected because they provide design-specific criteria for internal validity, are widely used in sports science systematic 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 coefficient and interpreted according to the Landis and Koch classification (slight, fair, moderate, substantial, or almost perfect agreement). Where the two reviewers' independent ratings were unavailable in a fully quantified form, a placeholder is retained indicating the position where the final kappa value and interpretation are to be reported once double-rating is finalised, in accordance with best practice for transparent SLR reporting. Studies were categorised as high, moderate or low quality based on the proportion of criteria met on the relevant JBI checklist (high: ≥ 80% criteria met; moderate: 50-79%; low: < 50%). Only studies of at least moderate quality were retained in the synthesis. Overall, the included body of literature was judged to be of moderate to high methodological quality, with the most common sources of risk of bias being incomplete blinding in intervention studies and modest sample sizes in cross-sectional comparisons; these limitations are considered when interpreting the synthesised findings.

A structured extraction form was used to record, for each included study: author(s), year of publication, country of first-author affiliation, study design, sample characteristics (sex, age, competitive level), the physical fitness characteristics assessed, the performance outcomes examined, and the key findings. The extracted data provided the input for the descriptive tables and the thematic synthesis. To reduce transcription error, extractions were cross-checked against the original full-text articles.

A limited bibliometric mapping was carried out to describe the distribution of included studies across publication years, geographic origin of the corresponding author's affiliation, and dominant thematic focus. This descriptive mapping supports interpretation of the qualitative synthesis but does not aim to constitute a full bibliometric analysis. No co-citation or co-authorship network analysis was performed, given the modest number of included studies.

Given the methodological heterogeneity of the included studies, 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. Each included study contributed to one or more themes, and cross-study patterns of agreement, divergence and gap were identified. Where possible, effect direction and magnitude were used to interpret the strength of the associations, though pooled quantitative estimates were not calculated due to heterogeneity of measurement. Reporting followed the PRISMA 2020 checklist (Page et al., 2021). The identification, screening, eligibility and inclusion stages are documented in the PRISMA 2020 flow diagram presented in Figure 1.

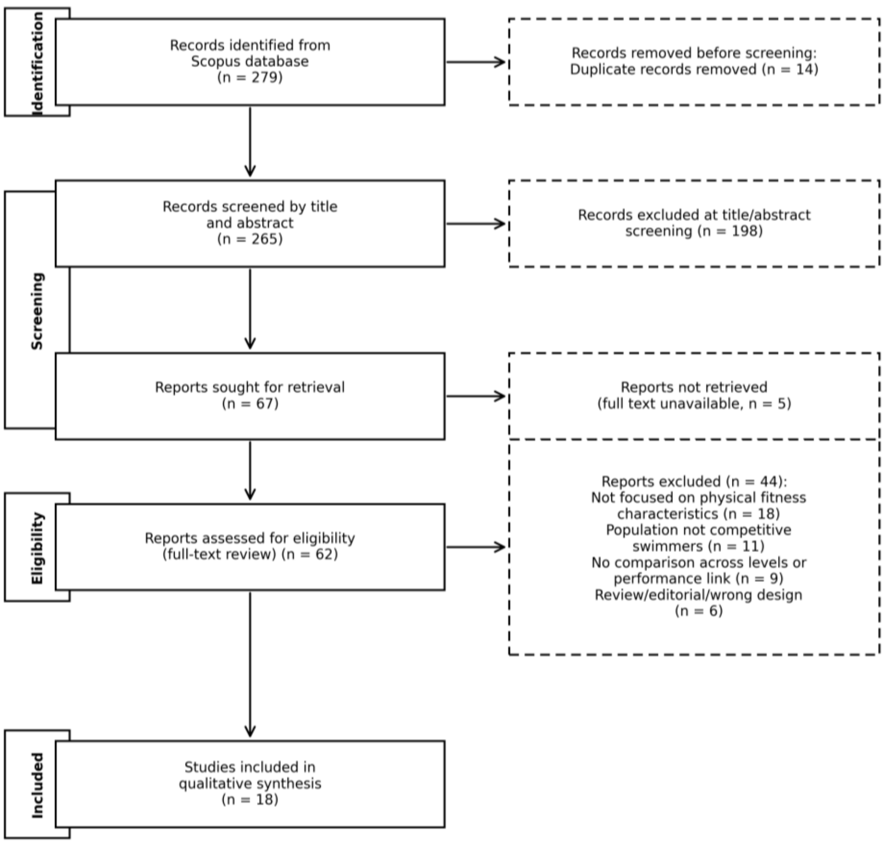

Figure 1. PRISMA 2020 flow diagram of the study identification, screening, eligibility and inclusion process.

Results and Discussion

The Scopus search identified 279 records. After removing 14 duplicates, 265 unique records were screened by title and abstract, and 198 records were excluded because they did not address competitive swimmers, physical fitness characteristics, or comparisons across competitive levels. A total of 67 reports were sought for retrieval; 5 could not be obtained in full text. The remaining 62 full-text reports were assessed for eligibility, and 44 were excluded because they did not focus on physical fitness characteristics (n = 18), sampled populations other than competitive swimmers (n = 11), did not report level comparisons or performance links (n = 9), or used inappropriate designs such as editorials or narrative reviews (n = 6). Eighteen studies met all criteria and were carried forward into synthesis (Figure 1). This 18-study final set is consistent across the abstract, methods, PRISMA flow diagram and results sections.

The 18 included studies were published between 1991 and 2026 and originated from thirteen countries, with a clear cluster of contributions from European and Asian research groups. Sample sizes ranged from small case series (n < 15) to cohorts of national- and international-level swimmers. Study designs included cross-sectional analyses (the most common), longitudinal tracking of talented swimmers, quasi-experimental intervention studies, and cluster-analysis approaches. Table 2 presents the summary characteristics of the included studies.

Table 2. Summary of Included Studies (n = 18)

Title	Author(s)	Year	Country	Method	Key Findings
Physical performance predictors in youth breaststroke swimming: motor and biomotor diagnostic differences	Karadenizli et al.	2026	Türkiye	Comparative cross-sectional	In 58 youth breaststroke swimmers (mean age 11.55 y), high-performance swimmers showed significantly greater agility, vertical jump height, balance, and arm span than low-performance peers; these motor and anthropometric variables were identified as key discriminators of breaststroke performance.
Tracking performance and its underlying characteristics in talented swimmers: a longitudinal study during the junior-to-senior transition	Post et al.	2023	Netherlands	Longitudinal	Talented sprint and middle-distance swimmers (n = 29) followed across four seasons showed that on-track swimmers had greater maximal swimming velocity, higher stroke index, and superior lower-body power than off-track peers during the junior-to-senior transition.
Physical function characteristics of swimmers in pre-competition training	Zhao & Li	2023	China	Applied cross-sectional	Analysis of physical composition and functional characteristics before competition indicated systematic changes in aerobic balance across age groups; physical function profiles varied consistently with competitive age, informing pre-competition programming.
The relationship between talent identification testing parameters and performance in elite junior swimmers	Mitchell et al.	2018	Australia	Cross-sectional	In 48 elite national-level junior swimmers, front-crawl critical speed showed the strongest correlations with competitive performance, whereas countermovement jump and anthropometric parameters made smaller but independent contributions.
Predicting dive start performance from kinematic variables at water entry in (sub-) elite swimmers	van Dijk et al.	2020	Netherlands	Cross-sectional biomechanical	Horizontal velocity of the centre of mass at water entry and the distance from the block were the strongest predictors of dive start performance in sub-elite and elite swimmers, exceeding the

					contribution of the body-water entry angle.
Baseline Functional Testing in Competitive Youth Swimmers	Naftilan et al.	2025	USA	Cross-sectional	The study established normative values for the closed kinetic chain upper extremity stability test and prone ball drop tests in competitive youth swimmers, providing age- and sex-referenced benchmarks for functional performance and return-to-sport decisions.
The prediction of swim start performance based on squat jump force-time characteristics	Thng et al.	2020	Australia	Cross-sectional / regression	Lower-body force-time predictors from the squat jump explained a substantial portion of the variance in swim start times to 5 m and 15 m in national and international swimmers, highlighting lower-body power as a key transferable capacity.
Physiological Responses During High-Intensity Interval Training in Young Swimmers	Almeida et al.	2021	Portugal	Cross-sectional experimental	In young swimmers, 100-m and 200-m interval sets performed at maximal aerobic velocity elicited comparable time spent near VO2peak but differed in blood lactate response and total time to exhaustion, informing interval prescription across age groups.
Laboratory-based tests for swimmers: Methodology, reliability, considerations and relationship with front-crawl performance	Dalamitros et al.	2014	Greece	Methodological review of primary tests	A synthesis of laboratory-based tests indicated that aerobic capacity, anaerobic power, and upper-body strength assessments show acceptable reliability and moderate-to-strong associations with front-crawl performance when standardised protocols are used.
Comparison of upper extremity physical characteristics between adolescent competitive swimmers and nonoverhead athletes	Hibberd et al.	2016	USA	Comparative cross-sectional	Adolescent competitive swimmers exhibited altered scapular kinematics, greater shoulder external-rotation range and reduced pectoralis minor length compared with nonoverhead athletes, indicating sport-specific adaptations of the upper extremity.
Effects of a 12-Week Detraining Period on Physical Capacity, Power, and Speed in Elite Swimmers	Głyk et al.	2022	Poland	Longitudinal quasi-experimental	In 14 elite swimmers, a 12-week detraining period led to meaningful decreases in lower- and upper-limb power and specific speed parameters, demonstrating the sensitivity of neuromuscular performance to reductions in training load at elite level.
Improved Neuromuscular Performance in Low-Load vs. Moderate-Load Resistance Training Among Young Elite Swimmers	Rodríguez-Rosell et al.	2026	Spain	Randomised controlled trial	In young elite swimmers, low-load (40-50% 1RM) resistance training performed with maximal intended velocity elicited improvements in neuromuscular performance comparable to moderate-load (55-65% 1RM) training, while reducing perceived fatigue.
The effect of preseason sport camp on strength	Bielec et al.	2025	Poland	Quasi-experimental pre-post	An 8-day preseason camp integrating pool and general fitness sessions produced

and speed abilities in youth swimmers					measurable gains in strength and speed capacities in youth swimmers aged 13-14 years, indicating short-term responsiveness of motor fitness to concentrated training.
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	An 8-week heavy-resistance core strength training programme improved upper-body strength and power in national-level junior athletes, including swimmers, with sport-specific responses observed between kayak sprinters and swimmers.
Start and turn performances of elite sprinters at the 2016 European Championships in swimming	Morais et al.	2019	Portugal	Observational competition analysis	Analysis of 64 male and female elite 100-m finalists at the 2016 European Championships showed stroke-specific differences in start and turn times, with freestyle producing the fastest turn parameters and butterfly the fastest male start times.
Young swimmers' classification based on kinematics, hydrodynamics, and anthropometrics	Barbosa et al.	2014	Portugal	Cluster analysis	Cluster analysis of 67 young swimmers identified performance-relevant groups differentiated by swimming velocity, speed fluctuation, active drag, and trunk transverse surface area, supporting a multivariate profiling approach to swimmer classification.
Physical characteristics in well-trained young swimmers	Demura et al.	1991	Japan	Comparative cross-sectional	Well-trained young competitive swimmers (n = 47) showed markedly different profiles from untrained peers on 53 physical parameters spanning morphology, strength and cardiorespiratory capacity, providing early foundational evidence of training-related fitness adaptations in youth.
Growing up and reaching for the top: A longitudinal study on swim performance and its underlying characteristics in talented swimmers	Post et al.	2024	Netherlands	Longitudinal	Ninety talented swimmers followed through their pubertal years showed that anthropometric development, maximal swimming velocity and stroke index progressively differentiated swimmers on track to elite status from those who were not.

Table 3. Study Classification by Theme, Design and Focus

Author(s)	Year	Country	Research Design	Primary Theme	Fitness Domain(s)	Outcome
Karadenizli et al.	2026	Türkiye	Comparative cross-sectional	Motor and biomotor predictors	Anthropometry, agility, power, balance	Breaststroke performance discrimination
Post et al.	2023	Netherlands	Longitudinal	Longitudinal performance tracking	Anthropometry, power, kinematics	Junior-to-senior transition status
Zhao & Li	2023	China	Applied cross-sectional	Pre-competition characterisation	Body composition, functional capacity	Aerobic balance profile
Mitchell et al.	2018	Australia	Cross-sectional	Talent identification correlates	Anthropometry, jump, aerobic capacity	Competition performance in juniors

Author(s)	Year	Country	Research Design	Primary Theme	Fitness Domain(s)	Outcome
van Dijk et al.	2020	Netherlands	Cross-sectional biomechanical	Kinematic performance	Dive start kinematics	Start time prediction
Naftilan et al.	2025	USA	Cross-sectional	Functional testing norms	Upper-extremity function, stability	Normative benchmarks
Thng et al.	2020	Australia	Cross-sectional / regression	Force-time predictors of start	Lower-body power	Swim start time
Almeida et al.	2021	Portugal	Cross-sectional experimental	Metabolic response to HIIT	Aerobic/anaerobic capacity	Physiological load characterisation
Dalamitros et al.	2014	Greece	Methodological review of primary tests	Test battery reliability	Aerobic, anaerobic, strength	Front-crawl performance link
Hibberd et al.	2016	USA	Comparative cross-sectional	Sport-specific adaptations	Upper-extremity ROM, posture	Adaptation vs comparator sports
Głyk et al.	2022	Poland	Longitudinal quasi-experimental	Detraining effects	Power, speed, capacity	Change in physical capacity
Rodríguez-Rosell et al.	2026	Spain	Randomised controlled trial	Resistance-training load comparison	Neuromuscular performance	Load-based adaptations
Bielec et al.	2025	Poland	Quasi-experimental pre-post	Camp-based training response	Strength and speed	Short-term motor gains
Saeterbakken et al.	2025	Norway	Quasi-experimental pilot	Core-strength intervention	Upper-body strength and power	Sport-specific gains
Morais et al.	2019	Portugal	Observational competition analysis	Elite competition analysis	Start and turn kinematics	Performance differentiation by stroke
Barbosa et al.	2014	Portugal	Cluster analysis	Multivariate classification	Kinematics, hydrodynamics, anthropometry	Cluster-based typology
Demura et al.	1991	Japan	Comparative cross-sectional	Foundational fitness profile	Morphology, strength, capacity	Trained vs untrained comparison
Post et al.	2024	Netherlands	Longitudinal	Longitudinal maturation profile	Anthropometry, velocity, stroke index	Elite-track differentiation

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

Author(s)	Year	Design	JBI Checklist Applied	Criteria Met	Overall Quality
Karadenizli et al.	2026	Cross-sectional	JBI - Analytical cross-sectional (8 items)	7/8	High
Post et al.	2023	Longitudinal cohort	JBI - Cohort (11 items)	9/11	High
Zhao & Li	2023	Cross-sectional	JBI - Analytical cross-sectional (8 items)	5/8	Moderate
Mitchell et al.	2018	Cross-sectional	JBI - Analytical cross-sectional (8 items)	7/8	High
van Dijk et al.	2020	Cross-sectional	JBI - Analytical cross-sectional (8 items)	7/8	High
Naftilan et al.	2025	Cross-sectional	JBI - Analytical cross-sectional (8 items)	6/8	Moderate
Thng et al.	2020	Cross-sectional	JBI - Analytical cross-sectional (8 items)	7/8	High
Almeida et al.	2021	Cross-sectional experimental	JBI - Quasi-experimental (9 items)	7/9	High
Dalamitros et al.	2014	Methodological review	JBI - Analytical cross-sectional (adapted)	6/8	Moderate
Hibberd et al.	2016	Cross-sectional	JBI - Analytical cross-sectional (8 items)	7/8	High
Głyk et al.	2022	Quasi-experimental	JBI - Quasi-experimental (9 items)	7/9	High
Rodríguez-Rosell et al.	2026	RCT	JBI - RCT (13 items)	11/13	High
Bielec et al.	2025	Quasi-experimental	JBI - Quasi-experimental (9 items)	6/9	Moderate
Saeterbakken et al.	2025	Quasi-experimental pilot	JBI - Quasi-experimental (9 items)	6/9	Moderate
Morais et al.	2019	Observational	JBI - Analytical cross-sectional (8 items)	7/8	High
Barbosa et al.	2014	Cluster analysis	JBI - Analytical cross-sectional (8 items)	6/8	Moderate
Demura et al.	1991	Cross-sectional	JBI - Analytical cross-sectional (8 items)	5/8	Moderate
Post et al.	2024	Longitudinal cohort	JBI - Cohort (11 items)	9/11	High

Inter-rater agreement for the JBI quality 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 moderate-to-high methodological quality across the included studies, with the most common deficiencies being incomplete blinding in intervention studies and modest sample sizes in cross-sectional comparisons.

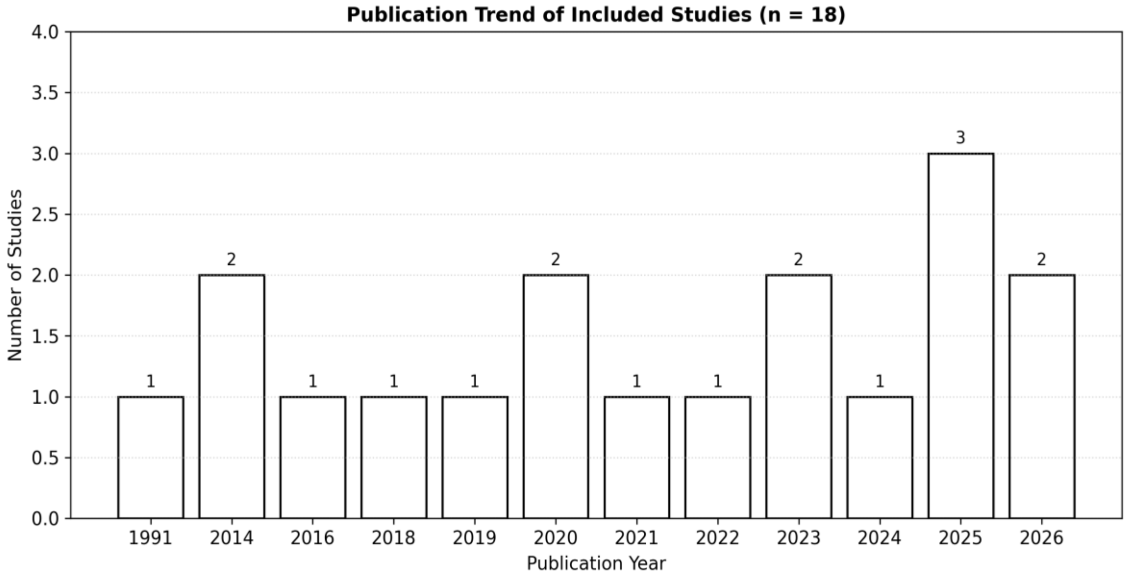

Figure 2. Publication trend of the 18 included studies, by publication year.

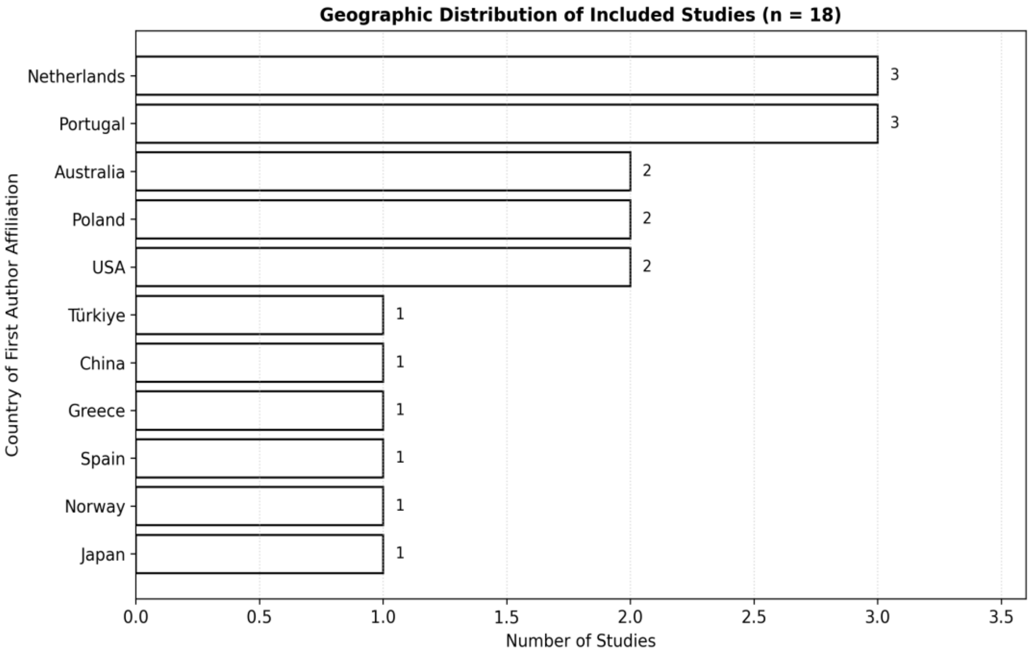

Figure 3. Geographic distribution of included studies by country of first-author affiliation.

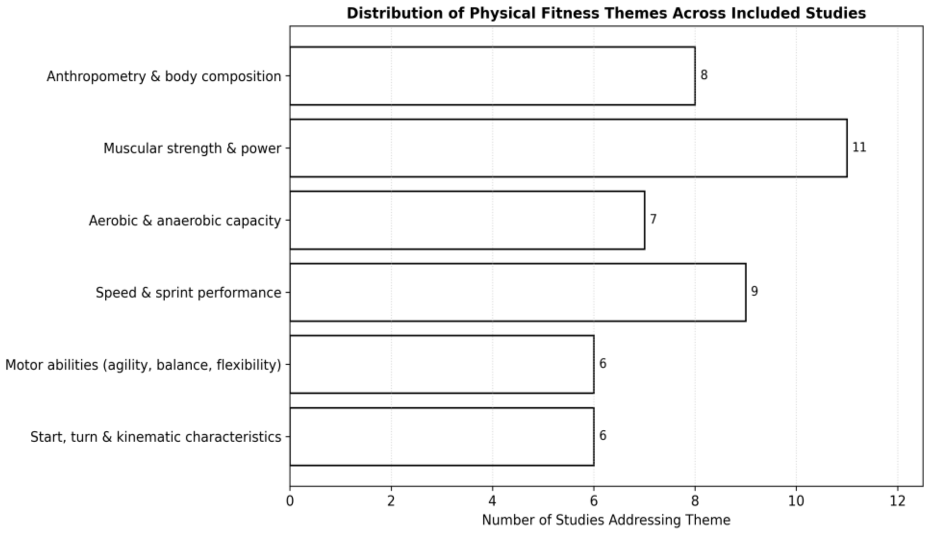

Figure 4. Distribution of physical fitness themes examined across the included studies. Studies may address more than one theme.

Thematic Synthesis

Findings for RQ1: Physical fitness characteristics investigated in competitive swimmers

The included evidence base characterised physical fitness in competitive swimmers through six broad domains: (i) anthropometric attributes; (ii) muscular strength and lower-body power; (iii) aerobic and anaerobic metabolic capacity; (iv) speed and sprint performance; (v) motor abilities such as agility, balance and flexibility; and (vi) technical-kinematic characteristics such as stroke index, start and turn parameters and hydrodynamic drag. Anthropometric variables-stature, body mass, arm span, trunk transverse surface area and body composition-were assessed in most of the included studies (Karadenizli et al., 2026; Post et al., 2023; Barbosa et al., 2014; Demura et al., 1991; Post et al., 2024). Muscular strength and power were commonly quantified using loaded and unloaded countermovement jumps, squat jumps and specific upper-body strength assessments (Mitchell et al., 2018; Thng et al., 2020; Głyk et al., 2022; Rodríguez-Rosell et al., 2026; Saeterbakken et al., 2025).

Aerobic and anaerobic capacity were captured through incremental step tests, critical speed determinations, and interval-based physiological profiling (Mitchell et al., 2018; Almeida et al., 2021; Dalamitros et al., 2014). Speed and sprint performance were tracked via 25-m and 50-m field trials and time-to-5 m or 15 m start assessments (Thng et al., 2020; Głyk et al., 2022; Bielec et al., 2025). Motor abilities such as agility, balance and grip strength were emphasised in youth-focused studies (Karadenizli et al., 2026; Naftilan et al., 2025). Technical-kinematic domains-active drag, stroke index and start and turn parameters-received particular attention at the elite level (Barbosa et al., 2014; Morais et al., 2019; van Dijk et al., 2020). This distribution is visualised in Figure 4 and demonstrates that competitive swimming is characterised via a multidimensional testing profile rather than any single dominant variable.

Findings for RQ2: Differences across competitive levels

Across the included studies, several consistent differences emerged between swimmers at different competitive levels. In youth swimmers, high performers were distinguished from low performers primarily by anthropometric and neuromuscular characteristics: greater arm span, higher vertical jump, better agility and superior balance (Karadenizli et al., 2026; Naftilan et al., 2025; Demura et al., 1991). Foundational evidence from Japan (Demura et al., 1991) established that well-trained young swimmers already differed markedly from untrained peers across 53 physical parameters spanning morphology, strength and capacity, underscoring the early emergence of a sport-specific fitness profile.

In talented junior swimmers, aerobic capacity indicators such as critical speed correlated most strongly with competition performance (Mitchell et al., 2018), while longitudinal tracking revealed that swimmers on track to elite status were differentiated by greater maximal swimming velocity, higher stroke index, and greater lower-body power than off-track peers (Post et al., 2023; Post et al., 2024). At sub-elite and elite levels, technical-kinematic parameters became increasingly discriminating: dive start kinematics and start/turn efficiency contributed disproportionately to performance (van Dijk et al., 2020; Morais et al., 2019). At elite level, the sensitivity of physical capacity to detraining-demonstrated by measurable declines in power and speed after a 12-week transition period (Głyk et al., 2022)-implies that maintenance of the neuromuscular profile becomes a defining feature of level retention rather than progression alone.

Findings for RQ3: Characteristics most consistently associated with higher competitive performance

Across the included evidence base, three sets of characteristics were most consistently associated with higher competitive performance in swimmers. First, lower-body force and power, quantified through squat and countermovement jump force-time profiles, emerged as robust predictors of start times and short-course sprint performance (Thng et al., 2020; van Dijk et al., 2020; Rodríguez-Rosell et al., 2026). Second, aerobic capacity-particularly front-crawl critical speed and maximal aerobic velocity-was strongly and reproducibly linked to competitive performance in junior swimmers (Mitchell et al., 2018; Almeida et al., 2021; Dalamitros et al., 2014).

Third, technical efficiency indicators, especially stroke index and maximal swimming velocity, showed longitudinal predictive value in swimmers on track to elite status (Post et al., 2023; Post et al., 2024; Barbosa et al., 2014). Anthropometric traits such as arm span and lean mass reinforced but did not replace these performance-related qualities. Interventions targeting core strength, low-load velocity-based resistance training and concentrated preseason camps produced measurable improvements in these underlying qualities (Saeterbakken et al., 2025; Rodríguez-Rosell et al., 2026; Bielec et al., 2025), supporting a modifiable performance-relevant fitness profile that can be shaped by training design.

Comparative and Critical Analysis of Methods

A comparative reading of the included evidence highlights three methodological patterns. First, cross-sectional designs dominate: they have provided rich descriptive profiles but constrain causal inference about how physical fitness characteristics develop across levels. Longitudinal designs, though far fewer in number, made the largest contribution to understanding the junior-to-senior transition (Post et al., 2023; Post et al., 2024). Second, test batteries are increasingly multidimensional: contemporary studies combine anthropometry, jump testing, aerobic profiling and kinematic analysis, whereas earlier studies typically focused on a single domain (Demura et al., 1991; Dalamitros et al., 2014). Third, intervention studies remain relatively scarce and heterogeneous, with pilot or quasi-experimental designs predominating over fully randomised trials (Głyk et al., 2022; Saeterbakken et al., 2025; Rodríguez-Rosell et al., 2026). Taken together, methodological evolution has favoured multivariate profiling, but the field would benefit from larger, adequately powered randomised interventions and from standardised reporting of testing protocols.

The findings of this systematic review indicate that physical fitness in competitive swimmers is best conceptualised as a multivariate construct in which anthropometric, neuromuscular, metabolic and technical-kinematic characteristics contribute jointly to performance. This conceptualisation aligns with converging evidence from broader sports science literature on aquatic sports (Crowley et al., 2022; Nugent et al., 2024) and reinforces the view that no single fitness attribute is sufficient to explain performance differentials across levels (Thng et al., 2020; Barbosa et al., 2014).

Theoretically, these findings extend existing models of long-term athlete development by supplying evidence-based benchmarks against which swimmers can be profiled at each competitive stage. The observation that on-track swimmers are differentiated by maximal swimming velocity, stroke index and lower-body power (Post et al., 2023; Post et al., 2024) supports developmental frameworks that emphasise the co-development of physical, technical and biomechanical qualities during the pubertal years. Foundational and comparative studies further indicate that these profiles emerge earlier in trained young swimmers than in untrained peers (Demura et al., 1991; Karadenizli et al., 2026).

Practically, the results have direct implications for talent identification, training design and monitoring. Coaches and sport scientists working with youth and junior swimmers may prioritise combined testing of arm span, vertical jump, agility and critical speed to construct a level-referenced fitness profile (Karadenizli et al., 2026; Mitchell et al., 2018; Naftilan et al., 2025). At sub-elite and elite levels, dive start kinematics and turn efficiency should be integrated into regular monitoring due to their disproportionate contribution to race outcomes (van Dijk et al., 2020; Morais et al., 2019). Programming choices such as velocity-based resistance training with lower relative loads, heavy-resistance core training, and structured preseason camps show promise for improving swim-relevant qualities in national-level athletes (Rodríguez-Rosell et al., 2026; Saeterbakken et al., 2025; Bielec et al., 2025).

Compared with prior reviews focused on strength training (Crowley et al., 2022) or on youth swimmers exclusively (Nugent et al., 2024), the present synthesis situates physical fitness characteristics within an explicit level-comparative frame. This broader framing helps to reconcile findings that might otherwise appear inconsistent when reported in isolation, such as the differing relative contribution of anthropometric versus neuromuscular variables across age groups and events (Karadenizli et al., 2026; Post et al., 2024). The added value of the current review lies in placing these primary findings into a coherent level-referenced schema rather than treating each attribute as an isolated marker of performance.

Some contradictions in the literature deserve explicit acknowledgement. For instance, while several studies identified lower-body power as the strongest predictor of swim start and sprint performance (Thng et al., 2020; van Dijk et al., 2020), others emphasise aerobic capacity or critical speed as the leading correlate of overall race performance in junior swimmers (Mitchell et al., 2018; Dalamitros et al., 2014). These divergent conclusions likely reflect differences in event distances, age bands and the level of competition sampled, and they highlight the need for stroke- and distance-specific interpretation frameworks (Almeida et al., 2021; Morais et al., 2019).

The synthesis also identifies several research gaps. Chief among them is the limited availability of longitudinal, multi-domain studies that follow swimmers across the full development pathway from age-group entry to senior international competition (Post et al., 2023; Post et al., 2024). This limits the field's capacity to model developmental trajectories and to disentangle maturation from training-induced adaptation. A related gap concerns the scarcity of randomised, adequately powered trials that compare training modalities on physical fitness and swim-specific outcomes (Rodríguez-Rosell et al., 2026; Saeterbakken et al., 2025).

This review has limitations. First, only the Scopus database was searched, which may have excluded relevant studies indexed elsewhere. Second, only English-language articles were included, potentially biasing findings toward research contexts where English-language publication is prevalent. Third, the modest final set of 18 studies, though appropriate for a focused qualitative synthesis, limits the depth of subgroup comparisons across strokes, sexes and event distances. Fourth, the methodological heterogeneity of the included studies precluded quantitative pooling.

Future research should therefore prioritise multi-site longitudinal cohorts of competitive swimmers that combine standardised anthropometric, neuromuscular, metabolic and kinematic assessments across the development pathway. Randomised trials comparing training modalities (e.g., velocity-based low-load vs moderate-load resistance training, heavy-resistance core work, technique-focused start and turn interventions) with swim-specific outcomes are strongly warranted (Rodríguez-Rosell et al., 2026; Saeterbakken et al., 2025). Standardisation of terminology and reporting across national federations would further enable cross-study comparisons and the construction of evidence-based benchmarks for talent identification and long-term athlete development.

In summary, this review answers the three research questions as follows. RQ1: physical fitness in competitive swimmers has been investigated across six overlapping domains-anthropometric, muscular strength/power, aerobic/anaerobic capacity, speed, motor abilities, and technical-kinematic characteristics. RQ2: swimmers at higher competitive levels are consistently distinguished by superior lower-body power, greater maximal swimming velocity, higher stroke index, and more efficient starts and turns; anthropometric and motor-ability differences are most pronounced in youth and junior samples. RQ3: the most reproducible correlates of higher competitive performance are lower-body force and power, aerobic capacity (particularly critical speed), and technical efficiency indices, together with supportive anthropometric traits.

Conclusions

This systematic review synthesised evidence from 18 studies published between 1991 and 2026 on the physical fitness characteristics of competitive swimmers across competitive levels. In answer to the three guiding research questions, the reviewed literature investigated six overlapping fitness domains—anthropometric, muscular strength and power, aerobic and anaerobic capacity, speed and sprint performance, motor abilities, and technical-kinematic characteristics. Swimmers at higher competitive levels were consistently differentiated by greater lower-body power, higher maximal swimming velocity, higher stroke index, and superior start and turn efficiency, with anthropometric and motor-ability differences most pronounced in youth and junior samples. The most reproducible correlates of higher performance were lower-body force and power, aerobic capacity (particularly critical speed), and technical efficiency indices. The core contribution of this review is an integrated, level-referenced framework of physical fitness characteristics that can inform three applied domains: (i) talent identification, by providing evidence-based benchmarks for each competitive level; (ii) monitoring, by identifying the most discriminatory characteristics to track longitudinally; and (iii) training prescription, by specifying the fitness qualities to develop at each stage of long-term athlete development. The review also highlights the need for standardised, longitudinal multi-domain testing protocols across national federations to enable cross-study comparability and the establishment of normative databases. The review is limited by its single-database search, English-language restriction, and the modest final study set, which preclude subgroup pooling. Future research should build multi-site longitudinal cohorts and randomised training trials that use standardised multidimensional testing so that swimmers, coaches, and sport scientists can benefit from a genuinely comparable evidence base. Until such studies are available, the integrated framework presented here provides the best available evidence-based guide for profiling swimmers across competitive levels and designing training programmes that target the characteristics most likely to enhance performance.

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