

Physiological Adaptations to Swimming and Aquatic Exercise: Critical Review

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ABSTRACT

Background: Swimming and aquatic exercise expose the body to buoyancy, hydrostatic pressure, resistance and a distinct thermal environment. These conditions may influence cardiovascular, metabolic and functional adaptations. Objective: To critically examine the adult evidence linking aquatic exercise with multisystem health outcomes while distinguishing swimming from upright water exercise. Methods: A critical narrative review was developed from the supplied literature set. Targeted checks of publisher and bibliographic records were used to correct study identities and assess selected findings. Evidence was organised by exercise mode, design, population and outcome; no pooled effect was calculated. Results: Selected controlled swimming trials reported improved endothelial function and blood pressure. A twelve-month comparison in older women found lower body weight and selected cholesterol measures with swimming than walking. Upright aquatic programmes provided additional evidence on aerobic fitness, strength and functional capacity. However, physiological responses differed across exercise modes, and statistical significance within one training group did not establish superiority over another. Evidence for a consistent rise in resting metabolic rate, uniform lipid improvement and stroke-specific benefits was insufficient. Conclusion: Aquatic exercise offers a useful setting for health-related training, with promising vascular, fitness and functional outcomes in selected adult populations. The magnitude and generalisability of benefits depend on programme design and participant characteristics. Larger controlled trials should report environmental conditions, exercise dose and between-group effects.

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1 Introduction

Swimming is performed in an environment that changes how the body is supported, how movement is resisted and how heat is exchanged. Its physiological interpretation therefore requires attention to the water environment as well as to the exercise itself. Lap swimming, deep-water running and shallow-water exercise share exposure to water, but they do not provide identical mechanical or cardiorespiratory demands. Reviews by Tanaka [1] and Meredith-Jones et al. [2] provide a useful basis for examining these differences.

The supplied literature addresses vascular function, aerobic capacity, lipids, body composition, muscular performance, mobility and perceived health. These outcomes belong to related but separate domains. An improvement in one marker cannot be taken as evidence that all systems improved. Similarly, a reduction in a cardiovascular risk marker does not directly demonstrate fewer cardiovascular events. These distinctions are necessary when interpreting relatively small exercise studies [1], [3].

The environmental physiology perspective is particularly relevant when aquatic programmes are proposed for adults

who find prolonged land exercise difficult. Water-supported movement can alter loading and allow different exercise choices. Nevertheless, the capacity to complete a programme depends on swimming ability, access, confidence and supervision. The practical suitability of an aquatic programme must therefore be considered alongside its measured physiological outcomes [1], [2].

This review examines how the aquatic environment relates to reported health adaptations. It also evaluates whether the study designs justify the conclusions drawn from them. Particular attention is given to separating swimming from other aquatic modalities and to identifying which findings may reasonably inform future freestyle and breaststroke research.

2 Review approach

This paper is a critical narrative review, rather than a systematic review or meta-analysis. The starting material was an author-assembled literature set covering swimming and aquatic health outcomes. On 16 October 2026, targeted web searches using author names, titles and outcome terms were used to locate publisher pages and PubMed records. The purpose was to resolve identifiable references and

verify selected methodological and numerical claims. This was not an exhaustive database search, and the paper does not claim complete coverage of the literature up to that date.

Adult human evidence relevant to swimming or aquatic exercise was prioritised. Primary intervention studies were used when identifiable; an acute comparative study was retained to explain environmental responses. Narrative reviews were used for context and were not counted as independent participant samples. Studies of upright aquatic exercise were retained because they inform the environmental argument, but their findings were not automatically attributed to lap swimming.

For the selected primary studies, the synthesis considered population, exercise mode, intervention duration, comparator and outcomes. Numerical results were retained only where the accessible publication record supported their meaning. Missing standard deviations, confidence intervals, sample sizes and p values were not reconstructed. Where only an abstract or bibliographic record was available, the interpretation was restricted accordingly. Table 1 summarises the selected evidence and its main interpretive limitations.

The review did not use protocol registration, exhaustive database searching, duplicate screening or an independent risk-of-bias assessment. Consequently, no PRISMA flow counts, formal certainty grades or pooled effects are presented. The methodological appraisal is qualitative and concerns causal inference, measurement specificity, comparator choice and applicability. This transparent scope avoids treating a selected literature set as an exhaustive systematic review.

3 Environmental mechanisms

Buoyancy and resistance are complementary features of water exercise. Buoyancy changes the support required during movement, whereas resistance changes with movement characteristics and the surface presented to the water. Their contribution differs between horizontal swimming and upright exercise. A participant may therefore experience low weight-bearing demand while still performing substantial muscular work. These properties explain the rationale for water-based training, but they do not by themselves establish the size of a chronic health benefit [1], [2].

Hydrostatic pressure and immersion influence circulation, while body position changes the context in which cardiovascular responses are measured. Fukuie et al. [4] examined head-out aquatic training, providing relevant evidence for central haemodynamics. However, an acute redistribution of blood during immersion and a persistent change after a training programme are different phenomena. A post-training measurement taken on land should not be interpreted as if it were simply the immediate effect of being in water.

Temperature also belongs in the description of an aquatic intervention. The water environment cannot be treated as a fixed exposure when thermal conditions differ. The present evidence does not support a general statement that swimming always expends more energy than a comparable land activity because of thermoregulation. Such a comparison requires direct measurement and careful matching of workload, exposure and participant characteristics [1], [2].

Environmental mechanisms should therefore be treated as plausible explanations unless directly tested. For example, improved flow-mediated dilation may be compatible with altered endothelial function, but it does not establish that nitric oxide production was measured or increased. Likewise, a change in peak oxygen uptake does not independently identify whether cardiac output, peripheral oxygen extraction or both changed. Figure 1 presents an explanatory framework rather than a tested causal model.

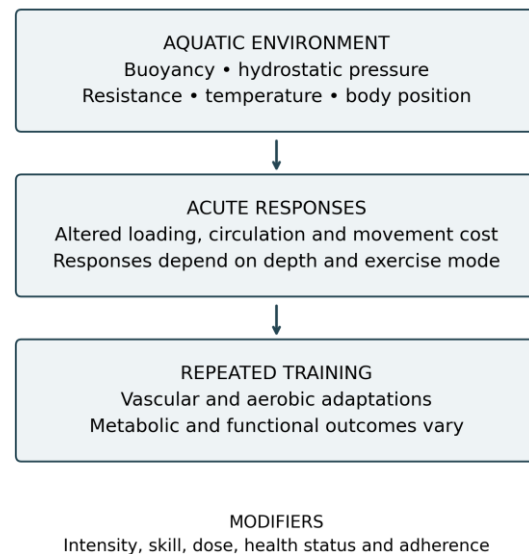


Figure 1. Environmental conditions, acute responses and possible training adaptations. Original conceptual synthesis informed by [1], [2] and [4]. Arrows indicate proposed relationships, not estimated effects. No participant data or pooled estimates are represented.

4 Characteristics of the evidence

The selected evidence includes controlled swimming interventions, an uncontrolled head-out exercise programme, aquatic resistance training and clinical functional exercise. This diversity broadens the health perspective but limits direct comparison. Table 1 retains the distinction between these interventions. Participant numbers refer to the population described in the accessible record; the analysed sample may differ from the number initially recruited.

5 Vascular function and haemodynamics

In ACELA II, Klonizakis and Mitropoulos [3] randomised 40 older adults to swimming or control conditions for eight weeks. The report presented post-intervention FMD values of $9.8 \pm 4.2\%$ in the swimming group and $4.6 \pm 2.5\%$ in controls, with $p < 0.001$. These values are group outcome levels, not percentage changes from baseline. The study supports a favourable vascular response in this setting, although its size and duration restrict wider inference.

Nualnim et al. [6] studied 43 otherwise healthy adults over 50 years with prehypertension or stage 1 hypertension who were not taking medication. Participants were randomised to 12 weeks of swimming or attention control. This design is directly relevant to swimming and vascular health. Its population, however, differs from younger normotensive adults; the result should not be treated as an identical expected response for every adult swimmer. Fukuie et al.

[4] reported aortic systolic pressure decreasing from 119 ± 15 to 115 ± 14 mmHg after head-out aquatic training in 23 analysed adults ($p = 0.005$). Brachial-ankle pulse wave velocity decreased from 1509 ± 301 to 1448 ± 296 cm/s ($p < 0.001$). These are within-sample pre-post findings. The absence of an inactive comparator limits attribution of the observed changes exclusively to training.

The measures used across these studies should remain distinct. FMD describes a vasodilator response, pulse wave

velocity relates to arterial stiffness, and central pressure describes a haemodynamic load. They do not constitute interchangeable measures of vascular health. Reporting them together is useful for a multisystem review, but calculating a common average improvement would conceal important physiological differences.

Farinha et al. [13] randomised 102 older adults among continuous aerobic, interval aerobic, combined aquatic and control groups for 28 weeks. The accessible abstract

Table 1. Characteristics of Included Studies Examining the Effects of Swimming on Health Variables

Author (Year)	Population & Study Design	Intervention (Type & Duration)	Key Variables Measured	Results/ Outcome Findings
Klonizakis & Mitropoulos (2023)	Older adults (n=40) RCT	8-week swimming program	FMD, microvascular function, QoL	Significant improvements in macro- and microvascular function; increased FMD and reduced waist circumference
Tang et al. (2022a)	Inactive adults (n=31) Experimental (HIIT vs MICT)	Aquatic HIIT vs MICT (short-term)	FMD, VO ₂ max	Both improved outcomes; HIIT showed superior gains in FMD and VO ₂ max
Farinha et al. (2022)	Older adults RCT	Aquatic exercise program	Lipids, IMT	Reduced carotid IMT; improved HDL and LDL levels
Moreira et al. (2020)	Older adults with musculoskeletal disorders RCT	Aquatic exercise	QoL, mobility	Improved mobility, strength, balance, and quality of life
Fukuie et al. (2021)	Middle-aged & elderly adults Experimental	Aquatic training	Aortic stiffness	Reduced arterial stiffness; improved vascular compliance
Cox et al. (2010)	Adults (older women) (n=116) Intervention study	12-month swimming (supervised + unsupervised)	BMI, lipid profile	Reduced BMI and total cholesterol; improved cardiovascular risk profile
Tanaka (2009)	Older adults Observational	Long-term swimming	VO ₂ max, arterial stiffness	Higher aerobic capacity and lower arterial stiffness vs sedentary individuals
Broman et al. (2006)	Healthy adults Comparative study	Aquatic vs land-based exercise	VO ₂ , HR, fitness	Comparable cardiovascular responses; improved tolerance and reduced joint stress
Colado et al. (2009)	Healthy adults Experimental	Water-based resistance training	BMI, fat %, strength	Reduced body fat; increased muscular strength
Takeshima et al. (2002)	Elderly women RCT	Water-based exercise program	VO ₂ max, strength	Improved aerobic capacity, strength, and flexibility
Meredith-Jones et al. (2011)	Overweight/obese adults Intervention study	Aquatic exercise	BMI, fat mass	Reduced body fat; improved body composition
Nualnim et al. (2012)	Middle-aged & older adults Training study	Swimming training (long-term)	Arterial stiffness	Reduced arterial stiffness; improved vascular function
Tanaka et al. (1997)	Adults (varied age & gender) Experimental	Swimming training	VO ₂ max	Significant increases in aerobic capacity across groups
Wang et al. (2013)	Adults Intervention study	Aquatic exercise	HDL, LDL, TG	Improved lipid metabolism; increased HDL, decreased LDL and TG
Lee & Oh (2014)	Adults Experimental	Water-based exercise training	RMR, BMI	Increased resting metabolic rate; reduced body fat
Volaklis et al. (2007)	Patients with CVD Systematic review	Various exercise modalities	Endothelial function	Exercise improves endothelial function (FMD), including aquatic exercise

Table 2. Summary of Physiological Effects of Swimming on Key Health Variables

Physiological Domain	Variables Assessed	Direction of Effect	Observed Physiological Adaptations	Supporting Studies
Vascular Function	Flow-mediated dilation (FMD), carotid intima-media thickness (IMT), arterial stiffness, microvascular conductance	↑ Improvement	Swimming enhances endothelial function through increased nitric oxide bioavailability, improves arterial compliance, reduces arterial stiffness, and promotes structural vascular remodeling (e.g., reduced IMT), thereby lowering cardiovascular risk	Klonizakis & Mitropoulos (2023); Tang et al. (2022a); Farinha et al. (2022); Fukuie et al. (2021); Nualnim et al. (2012)
Central Hemodynamics	Aortic pressure, vascular resistance, arterial compliance	↑ Improvement	Aquatic exercise improves central hemodynamics by reducing vascular resistance and enhancing aortic elasticity, leading to more efficient blood flow and reduced cardiac workload	Fukuie et al. (2021); Tang et al. (2022a)
Aerobic Capacity /Cardiorespiratory Fitness	VO ₂ max, heart rate (HR), stroke volume	↑ Increase	Swimming increases aerobic capacity through enhanced cardiac output, improved stroke volume, and greater peripheral oxygen extraction; it supports maintenance of cardiovascular fitness with aging	Tang et al. (2022a); Tanaka et al. (1997); Tanaka (2009); Broman et al. (2006)
Metabolic Health	Lipid profile (HDL, LDL, triglycerides), glucose, insulin sensitivity, resting metabolic rate (RMR)	↑ Improvement	Aquatic exercise improves lipid metabolism (↑ HDL, ↓ LDL and triglycerides), enhances insulin sensitivity, and increases resting metabolic rate, contributing to reduced cardiovascular and metabolic disease risk	Cox et al. (2010); Wang et al. (2013); Farinha et al. (2022); Lee & Oh (2014)
Body Composition	Body mass index (BMI), fat mass, body fat percentage, lean mass	↓ Fat / ↑ Lean mass	Swimming promotes reductions in body fat and BMI while improving lean muscle mass due to continuous water resistance and energy expenditure; particularly effective for overweight and obese individuals	Meredith-Jones et al. (2011); Colado et al. (2009); Cox et al. (2010)
Muscular Strength & Endurance	Muscle strength, endurance, flexibility	↑ Improvement	Water resistance enhances muscular strength and endurance, while buoyancy allows safe movement with reduced joint stress, improving overall musculoskeletal fitness	Colado et al. (2009); Takeshima et al. (2002); Moreira et al. (2020)
Functional Capacity	Mobility, balance, physical performance	↑ Improvement	Swimming improves functional independence by enhancing balance, coordination, and mobility, particularly in older adults and individuals with musculoskeletal disorders	Moreira et al. (2020); Takeshima et al. (2002)
Quality of Life (QoL)	Perceived health, physical function, mental well-being	↑ Improvement	Participation in aquatic exercise improves overall quality of life through physical improvements, reduced pain, increased independence, and psychological benefits	Klonizakis & Mitropoulos (2023); Moreira et al. (2020)
Comparative Exercise Response	Cardiovascular response, exercise tolerance	↔ Comparable / ↑ Favorable	Swimming can elicit cardiovascular and physiological responses comparable to land-based exercise while offering potential advantages such as reduced joint loading, improved exercise tolerance, enhanced adherence, and lower musculoskeletal stress.	Broman et al. (2006); Volaklis et al. (2007)

reported programme-specific differences in blood pressure, selected carotid haemodynamic measures, glucose and chemokines. The abstract-level evidence does not establish uniform improvement in HDL, LDL or carotid thickness across all programmes. Conclusions about these outcomes require outcome-specific examination of the full data.

The collective interpretation is favourable but bounded: selected aquatic interventions can modify vascular markers in particular adult groups. These trials do not establish prevention of myocardial infarction, stroke or cardiovascular mortality. Future studies should distinguish surrogate-marker improvement from clinical endpoints and provide estimates of between-group differences with confidence intervals.

6 Aerobic capacity and intensity

Takeshima et al. [8] studied 30 women aged 60–75 years allocated to training and control groups. The supervised 12-week programme involved water-based exercise three times weekly. Peak oxygen uptake increased by 12%, and oxygen uptake at lactate threshold increased by 20%, both reported at $p < 0.05$. This is evidence of improved aerobic fitness following a mixed water exercise programme, rather than evidence specific to freestyle or breaststroke.

Tang et al. [5] compared six weeks of aquatic HIIT and MICT. Aerobic fitness and endothelial function improved significantly within the HIIT group, while other responses favoured different outcomes within MICT. The report found no significant differences between the programmes in the principal haemodynamic, endothelial and aerobic fitness domains. These findings do not establish significantly superior gains from HIIT across the principal outcome domains.

This distinction is a central statistical issue. A significant pre-post change in one group and a non-significant change in another do not, by themselves, demonstrate a significant difference between groups. Superiority must be evaluated through a direct comparison, such as an appropriately specified interaction or baseline-adjusted outcome analysis. The conclusion should follow that comparison rather than the pattern of separate p values.

Acute exercise comparisons also require care. Broman et al. [11] compared deep-water running with treadmill running in older women. At maximal effort, oxygen uptake was 29% lower and heart rate 8% lower in water, with both differences reported at $p < 0.05$. This finding contradicts a blanket assumption that aquatic and land exercise always produce the same physiological response. It also cannot be used alone to infer the relative benefit of months of training.

For interpretation, the test mode and outcome definition must accompany the result. Peak oxygen uptake, measured maximal oxygen uptake and a field-test estimate should not all be labelled as directly measured $\dot{V}O_{2\max}$. A land test after swimming may indicate transfer of fitness, whereas a swim test is also influenced by technique. Future aquatic studies should state whether improved performance reflects physiological capacity, technical efficiency or a combination.

7 Metabolic health and body composition

Cox et al. [7] provide a useful direct comparison of swimming and walking in older women. At 12 months, swimming was associated with body weight 1.1 kg lower relative to walking ($p = 0.039$). Total cholesterol and LDL cholesterol were lower by 0.3 and 0.2 mmol/L, respectively ($p = 0.040$ and $p = 0.049$). These are comparative results from that trial and should not be presented as universal expected reductions.

The comparative design strengthens interpretation relative to a single-group study, but its demographic scope remains important. Findings in older sedentary women do not determine the magnitude of adaptation in recreationally active men aged 25–55 years. Baseline lipid concentrations, dietary intake, medication, exercise dose and changes in body weight are variables that future studies should record when examining metabolic outcomes.

Body composition should also be interpreted according to the measurement used. BMI is derived from mass and height and cannot separate fat from lean tissue. A fall in BMI therefore does not establish muscle gain or directly quantify fat loss. Studies using body fat percentage, waist circumference or lean mass address different aspects of composition. These outcomes should be reported separately rather than merged into one general statement of improvement.

Colado et al. [9] investigated aquatic resistance training in 46 sedentary postmenopausal women, with elastic-band and control comparisons. The study reported favourable fitness and body composition responses. It supports including resistance-oriented aquatic programmes in a wider health discussion, but does not show that ordinary lap swimming necessarily produces the same muscular adaptations.

A consistent increase in resting metabolic rate is not established by the verified evidence considered here. A change in body mass or fitness cannot substitute for a direct assessment of resting energy expenditure. Resting metabolic rate remains a reasonable future outcome, provided it is measured with a defined protocol; its direction of change must be determined from data.

Lipid responses require similarly selective wording. Evidence of lower total cholesterol or LDL in one trial cannot be expanded to include higher HDL, lower triglycerides and improved insulin sensitivity unless those outcomes were measured and supported. Wang et al. [12] examined flexibility, strength and aerobic fitness in osteoarthritis. Its findings should therefore inform the functional discussion rather than be used to substantiate lipid changes.

8 Muscular function and quality of life

Moreira et al. [10] randomised 120 older adults with musculoskeletal disorders and risk of falling to aquatic exercise or control conditions. The report supports benefits for functional capacity and perceptual outcomes, including quality of life and pain. This evidence is relevant to the practical value of water exercise, but the

intervention should not be relabelled as a lap-swimming programme.

Wang et al. [12] examined a 12-week aquatic programme in adults with hip or knee osteoarthritis. The study belongs in the fitness and functional domain. Together with the resistance study [9] and the older-women fitness trial [8], it indicates that the content of a water programme matters: strength, mobility and aerobic outcomes depend on the exercises actually performed.

A distinction is also needed between perceived improvement and objectively measured function. Quality-of-life questionnaires capture participants' experience, while strength or mobility tests assess specific performance tasks. Both are valuable, but they answer different questions. In unblinded exercise research, participants' expectations may affect self-reported outcomes, making a suitable comparator and consistent assessment procedures especially useful.

The evidence does not justify assuming that every swimmer will improve balance, independence or fall-related outcomes. Those conclusions require relevant measurements in the target population. For future research, the outcome should be selected according to the proposed pathway: for example, a mobility assessment for functional performance, a validated questionnaire for perceived health, and a strength test for muscular performance.

9 Comparative effectiveness and applicability

Aquatic and land exercise should be compared in terms of the outcome and population of interest. The Cox trial [7] offers a direct comparison for selected metabolic measures in older women. Broman et al. [11] examine immediate exercise responses in different environments. The two types of study cannot be combined into a claim that one environment is globally superior or that all physiological responses are equivalent.

Adherence is another outcome that needs direct evidence. ACELA II [3] reported compliance of 92.6% and 88.4% for twice- and thrice-weekly swimming schedules, respectively, over eight weeks. These findings support short-term feasibility in that setting. They do not establish higher adherence than land exercise, because the relevant comparator was not a land-training programme. Long-term participation and access need separate investigation.

For men aged 25–55 years, the present literature provides a rationale for research rather than a precise forecast of adaptation. Much of the selected evidence concerns older adults, postmenopausal women or clinical populations. A study in recreational swimmers should describe baseline ability and activity, because a technically skilled swimmer and a novice may perform the same distance at different physiological costs.

Freestyle and breaststroke should therefore be compared using a clearly defined exercise dose. Equal session duration does not guarantee equal intensity, distance or energy expenditure. Reporting distance, work and recovery periods, perceived exertion, heart rate where feasible, attendance and technique instruction would make the comparison more interpretable. These are

recommendations for study design; the selected evidence does not establish which stroke produces greater health benefits.

10 Measurement and research priorities

Table 2 translates the review into reporting priorities. Its purpose is to improve the interpretation of future studies rather than prescribe a universal training programme. Environmental exposure and the exercise dose should be described with enough detail to allow another researcher to understand what participants actually did. A controlled trial should define one primary outcome before analysis and explain the role of secondary outcomes. A study assessing many lipid, physiological and performance variables creates several opportunities for apparently significant results. Reporting all planned outcomes, effect estimates and uncertainty is more informative than selecting only p values below a threshold. Any multiplicity strategy should be stated and justified.

For two stroke groups measured before and after training, the central question is whether change differs between groups. A group-by-time model or a suitable baseline-adjusted analysis can address this question when its assumptions and design requirements are satisfied. Paired tests may describe within-group changes but do not replace a direct group comparison. This recommendation concerns future study analysis and is not a reanalysis of the published trials.

Future work should also distinguish immediate post-exercise effects from persistent training adaptations. Follow-up timing should be consistent between groups, and changes in medication, diet or other exercise should be documented. Longer observation would help determine whether benefits persist after supervised training ends. To establish environmental mechanisms, studies must measure the proposed mediator rather than infer it solely from a change in the final outcome.

11 Limitations

This review began with a selected reference set and used targeted verification rather than a comprehensive systematic search. Relevant studies may therefore have been missed. Some records were available only as abstracts or bibliographic entries, restricting extraction and appraisal. No independent duplicate review or formal risk-of-bias tool was applied, and no overall certainty rating is claimed.

The evidence also differs in population, aquatic modality, comparator, duration and measurement method. Small controlled studies and uncontrolled pre–post programmes contribute different levels of causal information. Positive findings may be more visible than null results in a selected source set. Consequently, the synthesis should be read as a critical interpretation of identifiable studies, with explicit gaps, rather than a quantitative estimate of the average benefit of swimming.

12 Conclusion

Selected adult studies support favourable vascular, aerobic, metabolic and functional outcomes after swimming or other aquatic exercise. The strongest

interpretation remains specific to the population, programme and outcome assessed. Swimming and upright aquatic exercise should be distinguished, and mechanisms should not be presented as measured adaptations unless directly investigated. The evidence does not establish universal HIIT superiority, consistent increases in resting metabolic rate or a preferred swimming stroke for health adaptation. Future controlled studies should report environmental conditions, training dose and direct between-group effects, with sufficient follow-up to assess durability.

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