REVIEW ARTICLE

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Effect of Resistance Training on Different Strokes of Swimming - A Systematic Review

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Abstract: Resistance training (RT) is widely recognized as a crucial component of preparation in swimming. Its impact on each swimming stroke remains unclear. Existing research has yielded inconsistent findings, and there is a need to synthesize the available evidence for more generalized knowledge in this area. This systematic review (SR) aimed to evaluate the effect of RT consisting of different resistance exercises (RE) in land as well as water medium on different strokes of swimming (SoS). This SR followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines with a PICOS (Population, Intervention, Comparison, Outcomes and Study) approach, for searching, reviewing, and evaluating the studies collected from six different databases (Google Scholar, PubMed, Scopus, SPORTDiscus, Web of Science, Research Gate). After inclusion and exclusion, 21 studies (conducted between 1993 and 2024) from different databases were included in the present SR for analysis and synthesis of more generalized knowledge on the impact of RT on different SoS. The study was registered in PROSPERO having no.: CRD420261301994. The methodological quality (MQ) was assessed using the Physiotherapy Evidence Database (PEDro) Scale, and the risk of bias (RoB) was calculated using the Cochrane RoB 2.0 tool. This study analyzed twenty-one randomized controlled trials (RCTs) that used stroke-specific swimming and incorporated RE, conducted on dry-land (dry-land resistance training: DLRT) & in-water (in-water resistance training: IWRT), and reported the impact of RT on different measures of swimming performance. The result revealed that both RT (DLRT & IWRT) improved swimming performance in all aspects, like starts, turns, and overall stroke mechanics. But there was no specific RE guidelines observed for performance enhancement, nor a specific RE schedule in individual swim strokes. Among the studies included in this SR, most of the studies investigated the impact of RT on freestyle, while backstroke and breaststroke, got only limited attention, however, no selected studies put attention on butterfly stroke this suggests that RT plays a crucial role in swimming strokes, particularly in freestyle, and to a lesser extent in backstroke, breaststroke. The findings put forth that future research should look at the effects of RT across all the strokes of swimming including backstroke, breaststroke, also need special attention on butterfly, which in turn will give us more clearer picture of how REs may be used to improve the performance in each SoS.

Keywords: Resistance Exercise, Strength Training, Dry-Land Training, Aquatic Training, Swimming Performance.

1. Introduction

Swimming performance depends on a complex interaction of technical efficiency, muscular strength, power output, and stroke-specific coordination. Over the years, researchers have highlighted that RT plays a crucial role in enhancing the propulsive forces required for all four competitive strokes: freestyle, backstroke, breaststroke, and butterfly (Aspenes & Karlsen, 2012; Girold *et al.,* 2006). Strength and power development have consistently been associated with improved sprint speed, stroke length, and overall mechanical efficiency in the water (Tanaka *et al.,* 1993). DLRT, including traditional weight training, elastic resistance, medicine-ball work, and functional strength exercises, has been shown to enhance parameters such as start performance, turn velocity, and swimming-specific power output (Crowley *et al.,* 2017; Della Tommasina *et al.,* 2023; Sadowski *et al.,* 2012). Likewise, in-water resisted swimming using tools such as parachutes, hand paddles, or tether systems has been reported to increase stroke propulsion and neuromuscular adaptation specific to swimming movements (García-Ramos *et al.,* 2016). Collectively, existing evidence suggests that RT, both dry-land and water-based plays an essential role in improving the biomechanical and physiological determinants of performance across different swimming strokes (Fadillah Amin *et al.,* 2024; Jin *et al.,* 2024).

Despite various research findings supporting the merits of RT for swimmers, there are several limitations too in the same domain of research. Most studies had short-term training interventions, usually spanning between 6 and 8 weeks, limiting the knowledge of long-term changes. Also, studies focused on experienced adult and adolescent swimmers (mostly, on experienced swimmers above 16 years of age). Previous SRs have examined the effects of RT on overall swimming performance and technical aspects specially stroke rate and stroke length (Crowley *et al.,* 2017), start and turn, short distance - strength and conditioning program, special care for injury prevention and rehabilitation (Amaro *et al.,* 2019), overall improvement of swimming performance due to DLRT, IWRT and different strength training methods (Fone & Van Den Tillaar, 2022). The earlier SRs neither provide outcomes related to different SoS nor IWRT & DLRT were precisely taken into consideration. Training protocols, equipment used, intensity and volume of exercise, as well as experience of the athlete, also show great variability, and therefore it is hard to extrapolate the current results to each stroke of swimming. The other significant weakness is that most studies examine the overall swimming performance (sprint time or race velocity) and not the stroke-specific performance, such as stroke rate, propulsive force, and stroke efficiency in each of the four strokes (Aspenes & Karlsen, 2012). In other studies, multi-component training programs are combined, so that strength training is combined with plyometrics, endurance, or technique work, and it is difficult to identify the direct effects of RTs. In addition, most of the existing research has small sample sizes or is predominantly about national level swimmers, which makes them inapplicable to elite or developmental athletes. The fact of what kind of RTs is beneficial to different strokes and whether some modalities have a more significant impact on performance outcomes is also unclear.

After finding the gaps, this SR seeks to resolve the gaps by synthesizing evidence available to establish the effects of RT on the stroke mechanics, performance parameters, and sport-specific adaptations in the freestyle, backstroke, breaststroke, and butterfly. This SR aims to clarify the most effective RT modalities and the areas of the research that require future investigation by concentrating on stroke-specific outcomes.

2. Materials & Methods

2.1 Search Strategy

An extensive literature search was carried out in various databases on the Internet, including Google Scholar, PubMed, SPORTDiscus, Scopus, Web of Science and ResearchGate. The period of extracted articles ranged from 1993 to 2024 and were searched until October 10 2025 with no restriction of time.

Table 1. Searched databases and associated search terms used

Databases	Search Terms
Google Scholar	"Swimming" AND "freestyle" OR "Backstroke" OR "Breaststroke" OR "Butterfly" OR "Resistance training" OR "Strength training".
PubMed	"Swimming" OR "Swimming strokes" AND "Resistance training".
SPORTDiscus	"Resistance training" OR "dry-land resistance" OR "in-water resistance training".
Web of Science	"Swimming performance" AND "strength training" OR "stroke mechanics".
ResearchGate	"Resistance training" AND "swimming" OR "swimming strokes"
SCOPUS	"Swimming performance" AND "strength training"

Only English language papers were selected for this specific study. Specific keywords, using Boolean operators, such as "swimming" AND "strength training", "dry-land resistance training" OR "in-water resistance training" AND "swimming performance", "resistance trainings" AND "freestyle" OR "backstroke" OR "breaststroke" OR "butterfly" were used to identify relevant studies (Table 1). The search terms were narrowed down and changed as needed to meet the indexing systems and the search needs of each database. This study was registered in PROSPERO with regd. No.: CRD420261301994.

2.2 Study Criteria

Inclusion in this SR was based on the study that had met certain criteria related to the aim of the study. Eligible studies were (i) those published in peer-reviewed journals that examined the implementation of RTs both on land and in water in swimming (ii) reported measurable outcomes related to the performance of different swimming strokes (iii) studies conducted on the subjects with different level of participants were included like regular, beginner, regional, competitive, national, elite-level, university, voluntary and specially abled swimmers with a view to investigate the impact of RT on different swimming stroke, however, these wide range of heterogeneity of population so included in the SR due to lack of specific studies on the impact of RT found in the domain of specific swimming strokes. (iv) had taken part in an organized RT or resistance-based swimming training (v) studies that explored various RT modalities. Conversely, this SR excluded research that (i) dealt with untrained, novice, master, triathletes and water-polo players, (ii) involved participants who suffered injuries or illnesses, and (iii) research that focused on overall performance in swimming.

The PICOS framework was used to structure the research question clearly. During the screening process, journal titles and author names were not blinded to the reviewers (Table 2).

2.3 Study Selection

The study selection was done in accordance with the Preferred Reporting Items of SRs and Meta-Analyses (PRISMA) to provide a clear and systematic methodology (Moher et al., 2009). The overall process of search and screening (Figure 1) was implemented progressively. First, journal titles were used to screen all the identified records and eliminate those that had duplicate records. The rest of the literature was then assessed on the basis of abstracts to find relevance to the study topic. Lastly, all articles were carefully revised to determine their eligibility and based on the preset inclusion and exclusion criteria, studies were either included or excluded.

Total records identified were 1231. Records screened after removing duplicates, ineligible and other miscellaneous reasons were 1109. After excluding 781 records, 328 were assessed. These records were again considered for inclusion and exclusion criteria. Finally, 21 studies were included for this SR.

Table 2. Eligibility criteria for the inclusion and exclusion of studies

PICOS	Inclusion Criteria	Exclusion Criteria
Population	Regular, beginner, regional, competitive, national, elite-level, university, voluntary, specially-abled swimmers	Untrained, novice, master, triathletes, water-polo players, swimmers with injuries or illnesses
Intervention	Resistance training programmes applied to swimming, including dry-land resistance training, in-water resistance training, or combined approaches	Studies without resistance training
Comparison	Control groups, traditional swim training, or alternative resistance or non-resistance training approaches	Studies without a comparison condition or pre and post assessment
Outcomes	Stroke-specific swimming performance	Studies reporting only overall swimming performance without stroke-specific outcomes
Study Design	Randomized controlled trials	Non-Randomized

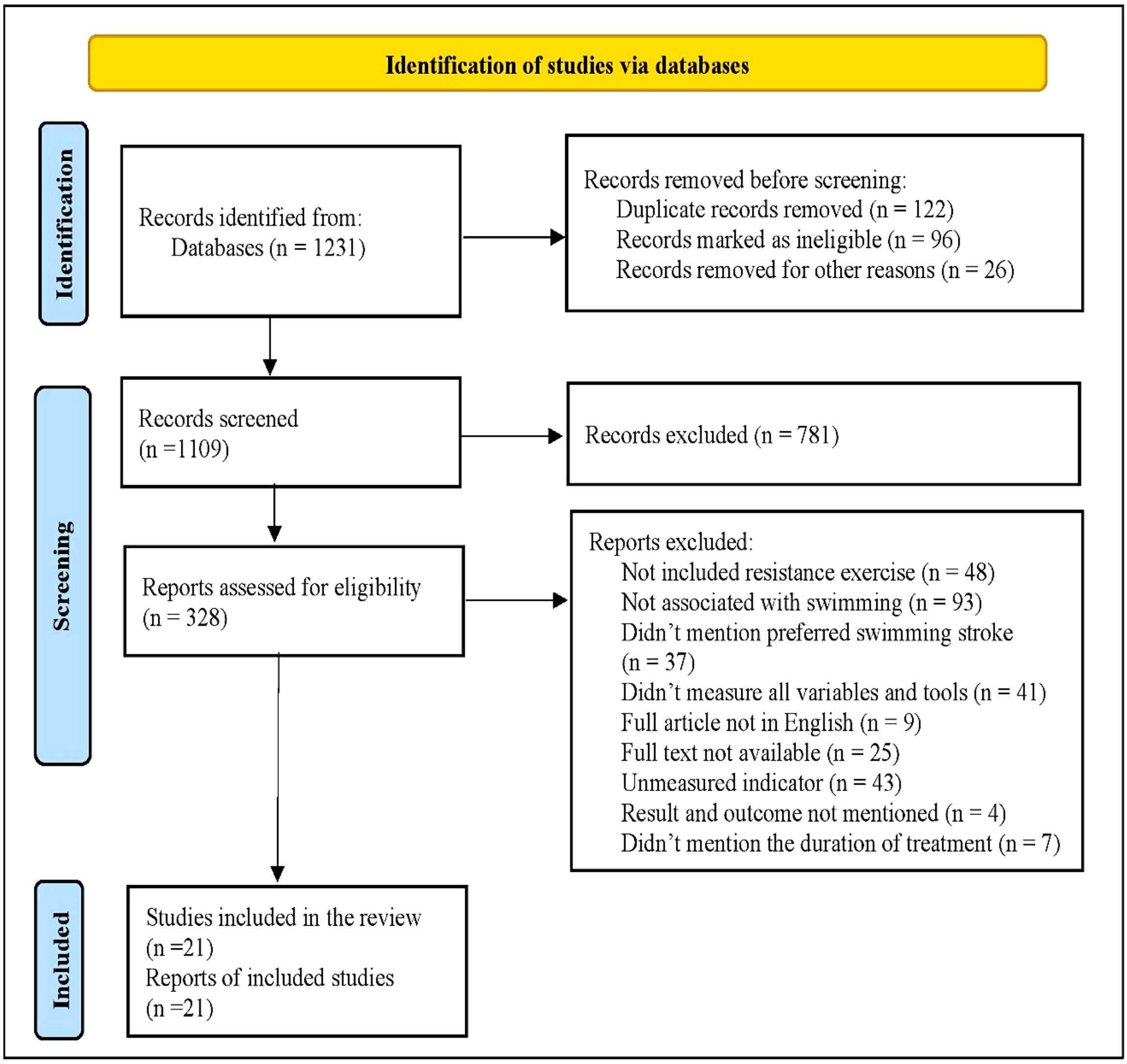

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart

2.4 Quality Assessment and Risk of Bias

2.4.1 Methodological Quality

The MQ of the studies was assessed using the Physiotherapy Evidence Database (PEDro) scale (Maher *et al.,* 2003). This tool includes 11 criteria that evaluate the methodological strength of research, such as participant eligibility, randomization technique, concealment of group allocation, similarity of groups at baseline, follow-up comparisons, and blinding of participants, therapists, and outcome assessors. It also examines whether the study used an intention-to-treat analysis, compared results between groups, and reported point estimates along with measures of variability. Each satisfied criterion receives one point, while unmet criteria receive zero. Based on the total score, studies are categorized as excellent (9-10 points), good (6-8 points), fair (4-5 points), or poor (below 4 points).

2.4.2 Risk of Bias

The risk of bias in the RCTs included in this review was examined using the Cochrane Risk of Bias 2 (RoB 2.0; edition 2019) tool (Sterne *et al.,* 2019). Each study was evaluated across five key domains, with specific guiding questions used to judge potential sources of bias within each domain. The final decision for each domain was made by following the step-by-step guidance provided in the RoB 2.0 framework, and categorises the level of bias as "low risk", "some concerns", or "high risk".

3. Results

Among the twenty-one (21) studies as included in this SR (Table 5), twelve (12) studies focused exclusively on DLRT (Sl. No, 1, 10, 11, 12, 13, 14, 15,16, 17, 18, 19 & 20 as shown in Table 5). Within this group, one study implemented a traditional strength-training approach using a tethered rubber device (Junior *et al.,* 2016). Three studies incorporated elastic tubing as the main form of resistance (Della Tommasina *et al.,* 2023; Girold *et al.,* 2006, 2007; Öner, 2019); another three relied on resistance bands (Hartono *et al.,* 2024; Ilham *et al.,* 2021; Sari *et al.,* 2023). Four studies applied Thera Band-based protocols (Gönener *et al.,* 2017; Selçuk Deyirmenci & Karacan, 2017; Yapıcı-Öksüzoğlu, 2020); and one study combined both assisted and resisted movements within its training design (Saleh Al-Shdoukhi *et al.,* 2022).

Five studies considered an integrated method involving the use of DLRTs, and the tools used included rubber bands or thera-bands with water- based RT. These combined interventions involved the use of parachutes, fins, hand paddles, specialized kicking sets and TheraBand exercises in water combined with traditional swim training (Amara *et al.,* 2022; Fadillah Amin *et al.,* 2024; Gül *et al.,* 2019; Liu *et al.,* 2024; Gromisz, 2020).

The number of studies concentrating on IWRT alone was only four out of 21 (Aktuğ *et al.,* 2019; Gourgoulis *et al.,* 2019; ĽUBOŠ *et al.,* 2018; Messinis *et al.,* 2014). Among these, one studied a combination of swimming drills and aquatic TheraBand exercises (Aktuğ *et al.*, 2019); another evaluated general in-water resistance methods (Gourgoulis *et al.,* 2019). One applied hand paddles as the primary intervention (Messinis *et al.,* 2014); and the remaining study employed a parachute-based resistance system (ĽUBOŠ *et al.,* 2018). The MQ of the included studies, evaluated using the PEDro scale, ranged from scores of 4 to 8 (Table 3). Two studies received a score of 4 (Gromisz, 2020; Messinis *et al.,* 2014), while five were rated with a score of 5 (Aktuğ et al., 2019; Öner, 2019; Saleh Al-Shdoukhi *et al.,* 2022; Sari *et al.,* 2023; Yapıcı-Öksüzoğlu, 2020). A larger group of studies achieved a score of 6 (Amara *et al.,* 2022; Girold *et al.,* 2006, 2007; Gourgoulis *et al.,* 2019; Gül *et al.,* 2019; Hartono *et al.,* 2024; Ilham *et al.,* 2021; Junior *et al.,* 2016; Liu *et al.,* 2024; ĽUBOŠ *et al.,* 2018; Selçuk Deyirmenci & Karacan, 2017; Fadillah Amin *et al.,* 2024; Gönener *et al.,* 2017).

Table 3. PEDro methodological quality rating scores

Sl. No.	Study	Criteria											Total PEDro Score
		1*	2	3	4	5	6	7	8	9	10	11	
1.	Gönener et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
2.	Yapıcı-Öksüzoğlu (2020)	1	0	0	1	0	0	0	1	1	1	1	**5**
3.	Fadillah Amin et al. (2024)	1	1	0	1	0	0	0	1	1	1	1	**6**
4.	Gromisz (2020)	1	1	0	1	0	0	0	1	1	0	0	**4**
5.	Hartono et al. (2024)	1	1	0	1	0	0	0	1	1	1	1	**6**
6.	Girold et al. (2007)	1	1	0	1	0	0	0	1	1	1	1	**6**
7.	Selçuk Deyirmenci & Karacan (2017)	1	1	0	1	0	0	0	1	1	1	1	**6**
8.	Ilham et al. (2021)	1	1	0	1	0	0	0	1	1	1	1	**6**
9.	Della Tommasina et al. (2023)	1	1	1	1	0	0	1	1	1	1	1	**8**
10.	Junior et al. (2016)	1	1	0	1	0	0	0	1	1	1	1	**6**
11.	Saleh Al-Shdoukhi et al. (2022)	1	0	0	1	0	0	0	1	1	1	1	**5**
12.	GÜL et al. (2019)	1	1	0	1	0	0	0	1	1	1	1	**6**
13.	Öner (2019)	1	0	0	1	0	0	0	1	1	1	1	**5**
14.	Girold et al. (2006)	1	1	0	1	0	0	0	1	1	1	1	**6**
15.	Aktuğ et al. (2019)	1	0	0	1	0	0	0	1	1	1	1	**5**
16.	Messinis et al. (2014)	1	0	0	1	0	0	0	1	1	0	1	**4**
17.	Ľuboš et al. (2018)	1	1	0	1	0	0	0	1	1	1	1	**6**
18.	Amara et al. (2022)	1	1	0	1	0	0	0	1	1	1	1	**6**
19.	Gourgoulis et al. (2019)	1	1	0	1	0	0	0	1	1	1	1	**6**
20.	Sari et al. (2023)	0	0	0	1	0	0	0	1	1	1	1	**5**
21.	Liu et al. (2024)	0	1	0	1	0	0	0	1	1	1	1	**6**

* Not counted toward total score

Only one study reached the highest score of 8 (Della Tommasina *et al*., 2023). All the studies included in this SR mentioned their study as RCTs in the paper, however, few of them did not clearly mention the process of randomization techniques they adopted that created complication to evaluate PEDro rating on different criteria (Aktuğ *et al.,* 2019; Messinis *et al.,* 2014; Öner, 2019; Saleh Al-Shdoukhi *et al.,* 2022; Sari *et al.,* 2023; Yapıcı-Öksüzoğlu, 2020). The remaining studies incorporated a control group in their research design.

The risk of bias in the RCTs was assessed using the Cochrane Risk of Bias 2.0 tool (Figure 2). For each domain, studies were rated as having "low risk", "some concerns" or "high risk". Among the included studies, four were judged to have "some concerns" related to bias (Della Tommasina *et al.,* 2023; Gönener et al., 2017; Hartono *et al.,* 2024; Messinis *et al.,* 2014), however, going through a thorough investigation using ROB 2.0 most of the studies (i.e., 17 studies) did not mention all the relevant information across each specific domain thus, leading them towards "high risk" of bias (Aktuğ *et al.,* 2019; Amara *et al.,* 2022; Fadillah Amin *et al.,* 2024; Girold et al., 2006, 2007; Gourgoulis *et al.*, 2019; Gül *et al.*, 2019; Ilham *et al.,* 2021; Junior *et al.,* 2016; Liu *et al.*, 2024; ĽUBOŠ *et al.,* 2018; Öner, 2019; Saleh Al-Shdoukhi *et al.,* 2022; Sari *et al.,* 2023; Selçuk Deyirmenci & Karacan, 2017; Gromisz, 2020; Yapıcı-Öksüzoğlu, 2020) and no studies were found to have "low risk" of bias (Figure 3). Thus, from here, through our SR we can say that there is a need for more experimental studies which will work keeping these things on mind.

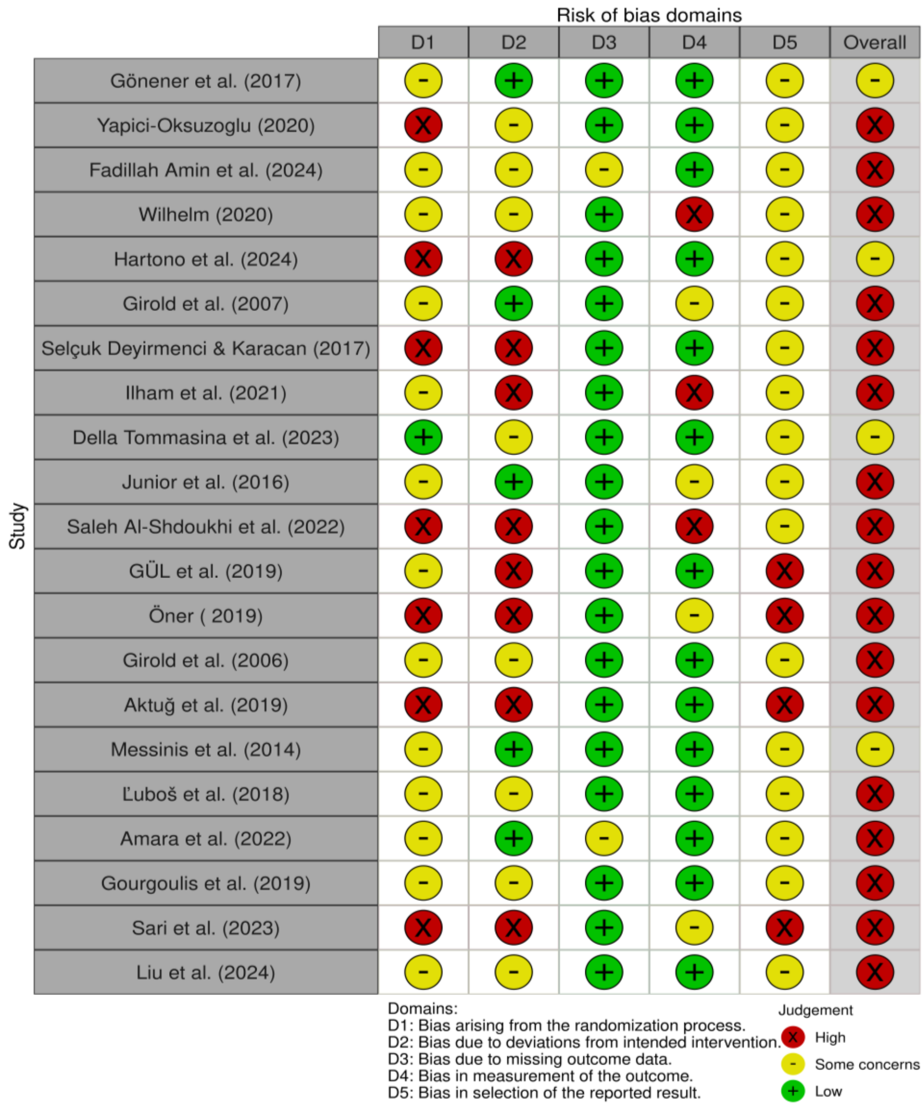

Figure 2. Traffic Light plots of the domain-level judgements for each result

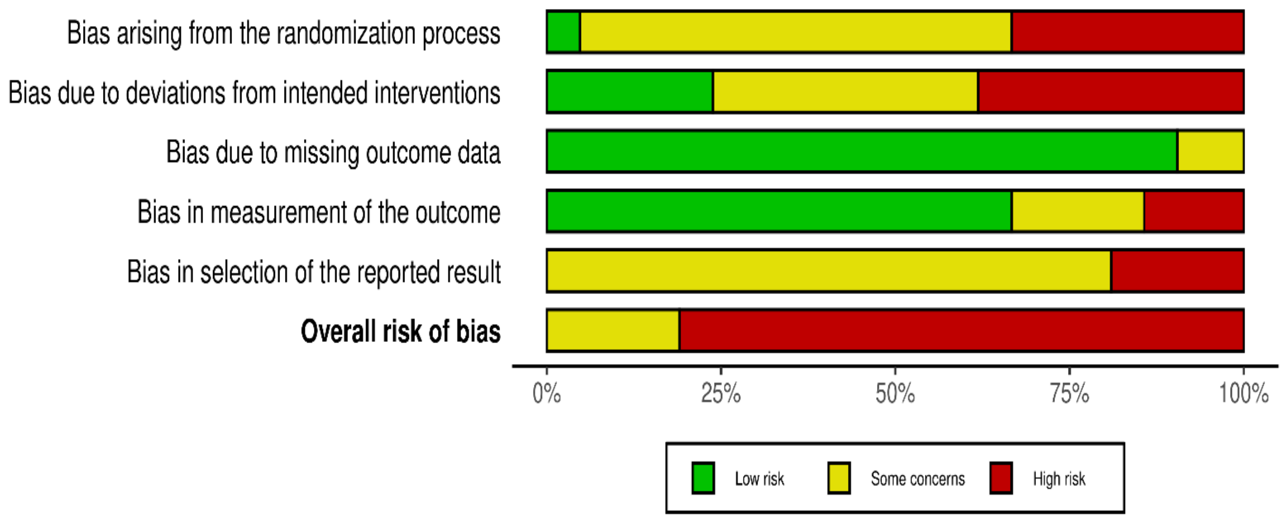

Figure 3. Weighted Bar Plots of the distribution of risk-of-bias judgements within each bias domain.

Table 4. Summary of Studies, Subject Background, Strokes, and Tools Used to Examine the Effect of Resistance Training on Swimming Performance

Sl No.	Author of the Article	Age (Y)	Sex	Level	N	Strokes	Variables: Tools Used to Measure
1.	Gönener *et al.* (2017)	13-15	M	Regular swimmer with ≥ 3 years of experience	N=20	Fr (100m)	1) SP: Stopwatch.
2.	Yapıcı-Öksüzoğlu (2020)	15-17	M	Regular swimmer	N=12	Fr (50m, 100m)	1) Anaerobic Performance: Wingate Arm & Leg Bike Ergometer, 2) Respiratory Parameters: Spirometer, 3) Shoulder Extension/Flexion Peak Torque: Cybex 4) SP:50m & 100m Fr.
3.	Fadillah Amin *et al.* (2024)	16-17	M	Elite adolescent athletes with disabilities (deaf) ≥ 6Y competitive swimming	N=48	Fr., Bk., & Br. (50m)	1) Physical Fitness: MS, Handgrip Strength, 2) Power: CMJ, 3) Endurance: YYIRTL1, 4) SP: Speed – Stopwatch
4.	Gromisz (2020)	21.2	M & F	Students of physical education	N=34	Fr. (25 m & 75 m)	1) Swimming Speed V (m/s), 2) Arm Frequency (cycles/min) and 3) Length of the Motor Cycle (m): Video Analysis.
5.	Hartono *et al.* (2024)	NM		Swimmers with physical disabilities	N=28	Fr. (50m)	1) SP: manual stopwatch
6.	Girold et al. (2007)	16.5	NM	Regional to the national level	N=21	Fr. (50m)	1) Forearm flexion-extension torque: Cybex, 2) Stroke Length, Rate & Depth: Picture Digitiser Software Pinnacle
7.	Selçuk Deyirmenci & Karacan (2017)	11-13	M	Regular swimmer with ≥ 2 years of experience	N=24	Fr. (25m & 50m)	1) SP: Manual Stopwatch
8.	Ilham *et al.* (2021)	>18	M & F	University students	N= 75	Fr. (25m)	1) SP: 25m Freestyle- Observation Sheet
9.	Della Tommasina *et al.* (2023)	18-33	M	University swimmers	N=22	Fr.	1)Maximum Isometric Strength-Dynamometer, 2) RoM: GM, 3) Muscular Balancer I/E R of each Arm 4) Scapulohumeral Coordination: PALM
10.	Junior *et al.* (2016)	15- 16	M	National Swimmers	N=24	Fr. (50m &25m)	MS: Maximum load lifted in a single movement
11.	Saleh Al-	15.4	M	Competitive	N=9,	Bk.	SP: Fr. 50m and 100m

	Shdoukhi *et al.* (2022)		& F	level	M=5, F=4	(50m-100m)	
12.	GÜL et al. (2019)	11-13	F	Regular Swimmer	N=21	Fr. (25-50-200m)	1) ME: Sit-up 30 seconds, 2) MS: push-up 30 seconds, 3) MS: medicine ball toss 30 seconds, 4) ELS: SBJ, and SP: Speed: Stopwatch
13.	Öner (2019)	11-14	M	Not mentioned	N=14	Fr. 25m,50m100m	SP: Speed, Stopwatch
14.	Girold *et al.* (2006)	14-21	M & F	Regional to the national level	N=37, M=16, F=21	Fr. (50m &25m)	1) Elbow extensor strength-isokinetic dynamometer (Cybex), 2) SP: Stopwatch, Stroke Rate-The Number of Strokes Per Minute (using a stroke base 3 stopwatch), stroke length-divide the mean velocity of each 50m by the mean stroke rate.
15.	Aktuğ *et al.* (2019)	11.67	M & F	Voluntary children	N=45	Fr. (50m)	1) SP: Stopwatch, 2) Motor Performance: Dordel Koch Test
16.	Messinis *et al.* (2014)	NM	NM	National level	N=8	Bk. (100m)	1) Heart Rate- Polar Monitor, 2) VO_2max- VAGA, 3) Rating of Perceived Exertion- 6-20 Borg scale 4) Blood Lactate-ALA, SP: Video Motion Analysis
17.	Ľuboš *et al.* (2018)	22.4	M	Performance swimmer	N=15	Fr. (12m, 25m)	1) Swimming Power: Swimming Isokinetic Dynamometer, 2) SP: Electronic Timer,
18.	Amara *et al.* (2022)	16.5	M	National level and 3years of RT experience, and 5 years of aquatic RT experience	N=22	Fr. (100m), start and turn	1) Lower body strength:1RM back squat, 2) leg kick-30mleg kick, SP: Stopwatch
19.	Gourgoulis *et al. (2019)*	12-14	M	Moderate performance level with 3-4 years of training experience, who regularly race short and middle distances	N=12	Fr. (50m)	1) SP: 50,100 & 200m, basic kinematic- stroke length, the stroke rate, and the duration of the propulsive and non-propulsive phases
20.	Sari *et al.* (2023)	NM	M & F	Beginner swimmer	N=12	Fr. (50m)	1) (Arm Muscle Strength- Time): SP: Stopwatch
21.	Liu *et al.* (2024)	15.1	M	National & regional age group breaststroker with 3 years of experience	N=24	Br. (50m & 200m)	1) Maximal Force, Mean Force, Fatigue Index: Tethered Swim Test, 2) lower limbs strength-1-RM back squat, 3) Anaerobic Critical Velocity: m/s 4) SP: Stopwatch

Not mentioned: NM, Muscular Strength: MS, Counter Movement Jump: CMJ, Swimming Performance: SP, Yo-Yo intermittent recovery test level 1: YYIRTL1, R I/E R: Ratio between Internal/External Rotators, Freestyle: Fr, Backstroke: Bk, Breaststroke: Br, Butterfly: Bf, Range of Motion: RoM, Goniometer: GM, ELS: Explosive Leg Strength, Validated Automatic Gas Analyser: VAGA, Automated Lactate Analyzer: ALA

Table 5. Summary of Interventions, Duration, Frequency, Intensity, Volume, and Outcome

Sl. No.	Author of the Article	Intervention	Duration	Frequency	Intensity	Volume	Results/ Outcomes
1.	Gönener et al. (2017)	12 different TB Trainings	8 weeks	3 days/ week	40-45 min; 15 min./set	55-60 min/sn	NSD between the EG & CG. But the difference between the intra-EGs was observed.
2.	Yapıcı-	TB exercises	6 weeks	3 times/	NM	NM	NSD between Pre-vs.

	Öksüzoğlu (2020)	consisting of 10 movements		week			Post-test in respiratory parameters, Anaerobic Performance Values and SP measurements in the EG, but a significant difference was observed in Shoulder Extension↑ & Flexion Values↑.
3.	Fadillah Amin *et al.* (2024)	Dryland + Aquatic exercises	7 weeks	2 days/ week	NM	NM	Handgrip Strength↑, CMJ↑, YIRTL1↑, SP↑ (increased for both EG & CG).
4.	Gromisz (2020)	DLRT with a rubber band, swim training + RAS	8 weeks	NM	300 Sec.	6sets x 50secs (10sec break)	Arm Frequency↑, Length of the Motor Cycle↑, Effect of RT program with a Resistance Rubber Band↓.
5.	Hartono *et al.* (2024)	Resistance Band	NM	NM	NM	NM	Speed↑.
6.	Girold *et al.* (2007)	Elastic Tube, Running, Cycling	12 weeks	6 training sessions/ week	80% and 90% of the Maximal Load	5,000 ± 500 m/ session	ST & RAST groups: Swimming Velocity↑, Strength of Elbow Flexors↑, Extensors↑, and Stroke Depth↓. Only RAST: Stroke Rate↑. NSDs in the SP between the ST and RAST groups were observed. NSD seen in the CG.
7.	Selçuk Deyirmenci & Karacan (2017)	TB	12 weeks	5 days/ week	NM	NM	SP↑
8.	Ilham *et al.* (2021)	Resistance Band	NM	18 sessions	NM	NM	Fr. skill↑
9.	Della Tommasina *et al.* (2023)	Elastic Bands	8 weeks	2 days/ week	NM	NM	NSD between EG & CG, NSD between intra-group, Isometric Strength↑
10.	Junior *et al.* (2016)	Tethered Rubber Device, Traditional ST	8 weeks	5 sessions/ week	NM	NM	NSD between Pre-vs. Post-test of each group. But there were differences in both groups that engaged in ST compared to the CG.
11.	Saleh Al-Shdoukhi *et al.* (2022)	Combined Assisted and RT	3 weeks	3 days/ week	NM	NM	SP of Bk: M 100m↑ (less↑ in F), 50m↑ (less↑ in M).
12.	GÜL *et al.* (2019)	TB in Land and Water	8-week	3 days/ week	NM	NM	Degrees of Swimming ↑, sit-ups ↑, push-ups↑, standing long jump ↑, and medicine ball toss↑.
13.	Öner (2019)	TB or Elastic Band	8 weeks	3 days/ week	NM	60-75 min/day	Fr. performance ↑
14.	Girold *et al.* (2006)	Elastic Tubes	3 weeks	6 days/ week	Moderate	45±5 km/week	RSOG: elbow extensor strength↑, swimming velocity↑, and SR↑, but SL remained unchanged. ASOG: SR↑ and SL ↓ without changes in swimming velocity.
15.	Aktuğ *et al.* (2019)	Swimming + Swimming Exercises, TB	8 weeks	3 days/ week	NM	35-40 min/sn	Side-Ward Jump↑, Flexibility↑, Standing Long Jump↑, Sit-Up↑,

							Balance↑, Push-Up↑, SP↑, but in 6-minute Running Performance no effect was observed.
16.	Messinis *et al.* (2014)	Hand Paddle	1 and 1/2 weeks	4 sessions; each at a 48 hr interval	Maximum 100% & Sub-max Intensity 85%	NM	Without Paddle: Stroke Length↓, Stroke Number↑, Gliding Length↑ (Both Intensities). Blood Lactate Conc.↑, Rating of Perceived Exertion↑ (Max. Intensity). Bk. with Paddles Efficacy ↑.
17.	Ľuboš *et al.* (2018)	Parachute Resistance	8 weeks	2 days/ week	Maximum	NM	SP↑, Power↑
18.	Amara *et al.* (2022)	DLRT & IWRT	9 weeks	4 sessions/week	NM	90 min/sn & 4-6 km/ session	Lower Body Strength↑ & Leg Kick SP↑
19.	Gourgoulis *et al.* (2019)	IWRT	11 weeks	4 sessions/ week	Maximum	NM	NSD in SL, SR & duration of the Propulsive & Non-Propulsive Phases. A positive effect was seen in SP due to an IWRT program.
20.	Sari *et al.* (2023)	Resistance Band	6weeks	3 times/week	NM	NM	Arm Strength↑
21.	Liu *et al.* (2024)	DLRT & IWRT, parachutes, fins, hand paddles & a specific kicking set.	10 weeks	2-3 sessions/ week	50-80% heart rate	NM	SP↑

Experimental Group: EG, Control Group: CG, Swimming Performance: SP, Counter Movement Jump: CMJ, Yo-Yo intermittent recovery test level 1: YYIRTL1, Minute/Session: min/sn, Thera-Band: TB, Increase: ↑, Decrease: ↓, Not mentioned: NM, Dry Land Resistance Training: DLRT, Resistance Arm Stroke: RAS, Resistive Assisted Sprint training: RAST, Strength training: ST, No significant difference: NSD, In-Water Resistance Training: IWRT, Resistance Training: RT, Combined With: +, Freestyle: Fr, Backstroke: Bk, Resisted-Sprint in Overstrength Group: RSOG, Assisted sprint in overspeed group: ASOG, Stroke Length: SL, Stroke Rate: SR.

4. Discussion

The studies included in this SR (21 studies) explored how different types of RT, both on land and in water, can influence swimming performance across various strokes. Strength training, on land or in the water directly, assists swimmers in enhancing the strength and control required to move faster and more efficiently in the water. Land-based training, like strength training and elastic resistance exercises or functional drills, was associated with improved starts, faster turns, and general enhancement of swimming-specific force production (Fone & Van Den Tillaar, 2022; Mavridis *et al.,* 2006; Tanaka *et al.,* 1993). The in-water resistance techniques, involving the incorporation of paddles, parachutes, or tethered devices, were useful to develop stroke power and technique adaptation that can promote more powerful propulsion (Kojima *et al.,* 2018; Zhu *et al.*, 2023). Others engaged in both land-based and in-water activities (Sadowski *et al.,* 2012). The majority of the included studies (eighteen) primarily investigated the impact of RT on freestyle swimming strokes, and some studies (only four) examined the effect of RT on the backstroke and breaststroke swimming strokes, but none of the studies (nil) investigated the effect of RT on the butterfly strokes in swimming (Table 4). The general trend across these studies was that RT tends to result in increased strength and power, improved stroke mechanics and short-distance swimming. These results showed similarity with previous studies (Girold *et al.*, 2006; Tanaka *et al.,* 1993), which indicated that muscular power is important in the production of propulsion in competitive swimming. Both the dry-land and in-water programs were effective, but the level of improvement differed based on the tools, the nature of the stroke, and the experience of the swimmers. This SR gives a concise overview of the applications of various approaches and their respective contributions to swimming performance.

The strength of this SR is its broad spectrum of resistance-training strategies that have been considered. A major strength here is the emphasis on stroke-specific outcomes and not on overall performance in swimming. Most of the previous studies examined time trials or sprint performance only, but swimmers do not use the same mechanics in all four strokes. By focusing on each of the strokes separately (freestyle, backstroke, breaststroke, and butterfly), this SR gives a deeper understanding of the impact of RT on the techniques and physical needs of each stroke. This fills a gap identified in the existing literature and provides a better insight into the most effective training methods to be used on a specific stroke. The included studies ranged from swimmers of different abilities, beginner swimmers and national level swimmers are also included in this SR. This broad spectrum simplifies the view of how different training techniques are effective at different developmental stages.

The results of this SR are mostly consistent with the previous studies, which have demonstrated the usefulness of RT in swimming. It has already been emphasized that strength and power training have the potential of enhancing sprint speed and performance in general (Girold *et al.,* 2007; Sadowski *et al.,* 2012), and the findings here report the same. Many of the studies included here showed enhancement in stroke rate, upper-body force exertion, leg power and swimming velocity, all of which support the notion that powerful muscles provide better propulsion in the water. Simultaneously, this SR goes a step further by juxtaposing the effects of various forms of RT, i.e., dry-land, in-water and combined training on swimming performance. Some evidence also indicated that combined programs (DLRT and IWRT) result in positive changes in strength and stroke mechanics. These results provide a better understanding of what already exists, especially the applicability and effects of RT, indicating that a synthesis of the two activities could be more advantageous.

The other contribution of this SR is that it clarifies IWRT does not harm the stroke technique. Some earlier discussions raised concern that the use of tools like hand paddles or parachutes might disturb stroke mechanics or timings, but studies included in this SR demonstrate that such tools may enhance performance without adversely impacting such important technical aspects (Gourgoulis *et al.,* 2019; Messinis *et al.,* 2014). This confirms that properly designed IWRT can develop power without affecting the efficiency of swimming (Sankar Ghosh & Biswas, 2023).

Thus, the findings support the established ideas in the field of swimming but also provide more accurate stroke-specific information. This SR helps in understanding which training methods can be most effective for specific performance goals by comparing the effects of various resistance tools, such as elastic bands, thera-bands, hand paddles, parachutes, and tethered systems. In this way, the review affirms previous results and also refines them by providing useful information to coaches and athletes to choose the most effective RT strategies.

The results of this SR indicate the areas in which further research should be conducted. Among these included studies, the clearest research gap is with respect to strokes other than freestyle (Table 6). Breaststroke and backstroke both have their different movement patterns and technical needs, which remain underrepresented in the existing evidence base. No traces of studies related to Butterfly stroke amalgamated with RT have been identified. It would be beneficial for future researchers to place more emphasis on these particular strokes as a means of obtaining a more balanced picture of the effects of various RT on swimming in general. There is a need for more longitudinal studies. The majority of the available programs vary for just a few weeks, which does not allow demonstrating how swimmers can adjust to RT in months or even during the competition phase. Long term interventions would aid in determining strength gain, plateau, or interaction with technique over time. One of the recurring problems in these literatures are that they are not standardized. Training loads, equipment selection, frequency of sessions and reporting methods differ a lot, particularly the methods of RT application and measurement.

In future, further in-depth investigation is needed on strength training and techniques. Though RT enhances the production of force, it should be combined with effective stroke mechanics. Research on these two factors, i.e., developing power along with technique, would be useful. More specific biomechanical data, like stroke phases, force application, and fatigue patterns, would enhance our understanding of the effect of RT. Most studies that currently exist incorporate strength training with other forms of conditioning, such as endurance or plyometrics, so it becomes difficult to isolate which factors are influenced by RT. The effects would be better separated by using more controlled study designs. Lastly, future studies should consider enrolling large and diverse populations of swimmers. A large part of the existing evidence is based on a small sample size. The findings should be more inclusive to the swimming community by including elite athletes, developing swimmers and broader age groups.

Table 6. Key effects for each stroke and training type:

Sl no.	Authors Of the article	Stroke	Training Type	Key effects
1	Gönener *et al.* (2017)	Fr	Resistance training	NSD between the EG & CG. But the difference between the intra-EGs was observed.
2	Yapıcı-Öksüzoğlu (2020)	Fr	Resistance training with movement	NSD between Pre-vs. Post-test in respiratory parameters, Anaerobic Performance Values and SP measurements in the EG, but a significant difference was observed in Shoulder Extension↑ & Flexion Values↑.
3	Fadillah Amin *et al.* (2024)	Fr., Bk., & Br.	Dry-land and aquatic exercise	Handgrip Strength↑, CMJ↑, YIRTL1↑, SP↑ (increased for both EG & CG).
4	Gromisz (2020)	Fr.	DLRT & RAS	Arm Frequency↑, Length of the Motor Cycle↑, Effect of RT program with a Resistance Rubber Band↓.
5	Hartono *et al.* (2024)	Fr.	RT	Speed↑.
6	Girold *et al.* (2007)	Fr.	Elastic Tube, Running, Cycling	ST & RAST groups: Swimming Velocity↑, Strength of Elbow Flexors↑, Extensors↑, and Stroke Depth↓. Only RAST: Stroke Rate↑. NSDs in the SP between the ST and RAST groups were observed. NSD seen in the CG.
7	Selçuk Deyirmenci & Karacan (2017)	Fr.	RT with TheraBand	SP↑
8	Ilham *et al.* (2021)	Fr.	RT with resistance band	Fr. skill↑
9	Della Tommasina *et al.* (2023)	Fr.	RT with elastic bands	NSD between EG & CG, NSD between intra-group, Isometric Strength↑
10	Junior *et al.* (2016)	Fr.	Tethered Rubber Device, Traditional ST	NSD between Pre-vs. Post-test of each group. But there were differences in both groups that engaged in ST compared to the CG.
11	Saleh Al-Shdoukhi *et al.* (2022)	Bk.	RT	SP of Bk: M 100m↑ (less↑ in F), 50m↑ (less↑ in M).
12	GÜL *et al.* (2019)	Fr.	RT (land and water).	Degrees of Swimming ↑, sit-ups ↑, push-ups↑, standing long jump ↑, and medicine ball toss↑.
13	Öner (2019)	Fr.	RT with thera-band	Fr. performance ↑
14	Girold *et al.* (2006)	Fr.	RT with elastic tube	RSOG: elbow extensor strength↑, swimming velocity↑, and SR↑, but SL remained unchanged. ASOG: SR↑ and SL ↓ without changes in swimming velocity.
15	Aktuğ *et al.* (2019)	Fr.	RT with thera-band	Side-Ward Jump↑, Flexibility↑, Standing Long Jump↑, Sit-Up↑, Balance↑, Push-Up↑, SP↑ but in 6-minute Running Performance no effect was observed.
16	Messinis *et al.* (2014)	Bk.	RT with hand paddle	Without Paddle: Stroke Length↓, Stroke Number↑, Gliding Length↑ (Both Intensities). Blood Lactate Conc.↑, Rating of Perceived Exertion↑ (Max. Intensity). Bk. with Paddles Efficacy ↑.

17	Ľuboš *et al.* (2018)	Fr.	RT with parachute	SP↑, Power↑
18	Amara *et al.* (2022)	Fr.	RT (dry and water)	Lower Body Strength↑ & Leg Kick SP↑
19	Gourgoulis et al. (2019)	Fr.	RT (water)	NSD in SL, SR & duration of the Propulsive & Non-Propulsive Phases. A positive effect was seen in SP due to an IWRT program.
20	Sari et al. (2023)	Fr.	RT with band	Arm Strength↑
21	Liu et al. (2024)	Br.	RT	SP↑

Experimental Group: EG, Control Group: CG, Swimming Performance: SP, Counter Movement Jump: CMJ, Yo-Yo intermittent recovery test level 1: YYIRTL1, Minute/Session: min/sn, Thera-Band: TB, Increase: ↑, Decrease: ↓, Not mentioned: NM, Dry Land Resistance Training: DLRT, Resistance Arm Stroke: RAS, Resistive Assisted Sprint training: RAST, Strength training: ST, No Significant Difference: NSD, In-Water Resistance Training: IWRT, Resistance Training: RT, Combined With: +, Freestyle: Fr, Backstroke: Bk, Resisted-Sprint in Overstrength Group: RSOG, Assisted sprint in overspeed group: ASOG, Stroke Length: SL, Stroke Rate: SR.

In table 6 summary of the discussion indicated the impact of RT of different performance variables with respect to specific stroke and training modalities.

It was observed from table 6 that 18 studies out of twenty-one investigated the impact of RT on freestyle, on the other hand only 2 and 3 studies investigated the impact of RT on breaststroke and backstroke respectively. Whereas no single study was identified on the impact of RT on butterfly. But most of the included studies showed significant improvement on different stroke performance variables due to the intervention of various resistance training modalities. Among the included studies conducted on different stroke in swimming, freestyle was studied mostly. It was also observed that irrespective of age and stroke pattern, it confirms that performance improved for different level of swimmer in the different strokes (freestyle, breaststroke and backstroke) for few studies, however, in few studies the result reflected that RT had no significant impact on stroke length, speed and respiratory variables of the swimmers. In the included studies different resistance training modalities were used in dry land as well as in aquatic medium, sometimes few studies used elastic rubber band/ theraband where elasticity was used as resistance and few studies used gravitational pull as resistance, whereas some studies used water/air resistance by using parachute and hand paddle. Irrespective of any means of RT, most of the studies showed significant impact of RT on swimming performance particularly on freestyle, breaststroke and backstroke, except in few cases.

4.1 Limitations

The studies included in this SR were typically heterogeneous from the stand point of population, age, level of participation, research designs and so on, made it difficult to generalize the conclusion. Most of the interventions were short-term, usually from six to ten weeks, thereby rendering uncertainty on the long-term impacts of RT on stroke performance. Earlier reviews have pointed out similar concerns, showing that most available research focuses on short training periods rather than sustained development over time (Crowley *et al.*, 2017). Another limitation was the lack of stroke-specific previous research. Freestyle was the mostly studied (Aktuğ *et al.*, 2019; Amara *et al.,* 2022; Della Tommasina *et al.*, 2023; Fadillah Amin *et al.,* 2024; Girold *et al.,* 2006, 2007; Gönener *et al.,* 2017; Gourgoulis *et al.*, 2019; Gül *et al.,* 2019; Hartono *et al.,* 2024; Ilham *et al.,* 2021; Junior *et al.,* 2016; ĽUBOŠ *et al.,* 2018; Öner, 2019; Sari *et al.*, 2023; Selçuk Deyirmenci & Karacan, 2017; Gromisz, 2020; Yapıcı-Öksüzoğlu, 2020), while backstroke and breaststroke received much less attention (Fadillah Amin *et al.*, 2024; Liu *et al.*, 2024; Messinis *et al.,* 2014; Saleh Al-Shdoukhi et al., 2022) and no specific study on butterfly was found in this direction. A further problem across the literature is the heterogeneity of training protocol used by the selected studies in this SR. The RT programmes varied between basic elastic-band exercises and complicated land-based strength training and water resistance equipment such as parachutes or hand paddles. The frequency, intensity and the purpose of these exercises were not constant. To provide consistency despite this diversity, we grouped the studies into dry-land, in-water, and combined (DLRT & IWRT) programmes, and noticed the equipment used in each. This screening helped to highlight patterns which would have been forgotten in the variation. Another limitation is that many studies reported only overall swimming time, not specifically detailed specific attributes in each stroke, such as propulsive force, stroke length or mechanical efficiency. Thus, it becomes difficult to understand why performance improved and how RT affects each stroke differently. Other researchers added other training exercises such as endurance or plyometrics thus it was hard to determine the impact of RT alone. Small sample sizes in maximum studies, along with the frequent focus on swimmers' performance level, usually regional or national, tend to restrict the applicability of the results. Consequently, the outcomes may not truly represent elite swimmers, younger developing swimmers, or swimmers with different training histories.

5. Conclusions

This SR highlights the significant impact of RT on different strokes of swimming, precisely freestyle, backstroke and breaststroke. Both land-based and in-water training modalities showed beneficial effect to some extent towards these swimming strokes. The analysis of 21 studies, though, revealed that RT enhances critical aspects of swimming, such as starts, turns, and overall stroke mechanics, but it neither mentioned the specific RT that is responsible for the performance enhancement nor worked stroke-specifically. Notably, while some research has shown RT to have considerable benefits for freestyle swimming, there remains a gap in research regarding its effects on backstroke, breaststroke and butterfly. This SR supports the notion that RT for each stroke is very crucial, as the needs of each stroke-specific swimmer are different. Future studies should aim to explore the effects of RT across all strokes, particularly focusing on backstroke, breaststroke and butterfly, to provide a more comprehensive understanding of how RT and specifically which RT, can optimise stroke-specific swimming performance.

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Sandip Sankar Ghosh: Conceptualization, Methodology, Formal Analysis, Writing - Original Draft. Ozoswi Banerjee: Conceptualization, Methodology, Investigation. Sanjhdipa Naskar: Validation, Formal analysis. Sanjoy Khan- Writing - Review & Editing. Atithi Biswas: Writing - Review & Editing. Suman Saha: Writing - Review & Editing. All the authors read and approved the final version of this manuscript.

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