Scoping Review Article – Title Page

Title: Inter-Limb Asymmetries in Swimming and their Impact on Performance: Evidence from a Scoping Review

Running Head: Inter-Limb Asymmetries in Swimming

Authors: Debora Knihs, Chris Bishop, Haiko Zimmerman and Juliano Dal Pupo

Key Words: Bilateral difference; Dry-land test; In-water test; Swimmer; Sports science; Biomechanics.

Conflicts of Interest and Source of Funding: The authors report no conflicts of interest and no source of funding.

ABSTRACT

The objectives of the present review were to: (a) map the studies analyzing bilateral asymmetries in specific (in-water tests) and non-specific (dry-land tests) swimming contexts and (b) investigate the effects of inter-limb asymmetries on swimming performance. Searches were systematically conducted on four databases. Out of 768 studies examined, 60 were eligible for the final selection (https://osf.io/46gya). Twenty-eight studies analyzed asymmetries during in-water tests, with asymmetry values ranging from 2.7 to 60.0%, and most studies (n = 18) reported significant between-limb differences ($p < 0.05$). Asymmetries were also analyzed during dry-land tests in 24 studies, with asymmetry values ranging from 1.1 to 16.6%. Interestingly, most of these studies (n = 12) did not verify any significant between-limb differences ($p > 0.05$). Eight studies measured asymmetries in both contexts and reported asymmetry values from -24.1 to 17.4%, with four studies finding significant differences between body sides ($p < 0.05$). Seven of the 60 studies selected investigated the relationship between asymmetries and swimming performance, with five reporting no meaningful associations with swimming performance. In conclusion, significant asymmetries in swimming are more evident during in-water than during dry-land tests. In addition, the few studies investigating asymmetries' influence on swimming performance reported that asymmetries rarely impact swimming performance.

INTRODUCTION

Bilateral asymmetry refers to differences between sides of the body and has drawn the attention of researchers in sports science, with a significant increase in the number of studies in the last decade (15,48). This recent interest in the topic is mainly due to its possible effects on physical and sports performance (15,48). For example, inter-limb asymmetries in force production are detrimental to jump performance (2). In addition, asymmetries from unilateral jumps and change of direction tests have been associated with reduced sprint performance (13,46). Furthermore, asymmetries may also be related to injuries (20,37). However, more studies are necessary to determine whether pre-existing imbalances are a potential risk factor.

Factors related to the type of sport and amount of time training and competing have been suggested as reasons why inter-limb asymmetries likely develop in athletes (28,41,48). In addition, greater chronic and repeated exposure of one limb during training in sports where unilateral movement competency is required (e.g., tennis, soccer, volleyball) can generate adaptations in that limb that do not develop in the same way on the contralateral limb (48). This is logical in acyclic sports, where one limb may have different demands than the other (48). However, in cyclical sports such as swimming, running, and cycling, both limbs (theoretically) perform equal movements with the same demand, although alternately (48). Specifically, in swimming, both arms and both legs must work similarly in movement pattern and propulsive force generation (19,27,63). The symmetrical “work” between limbs allows correct body alignment to be maintained (68) and minimizes resistance drag in the water (70). In addition, equal use of both arms can decrease intra-cycle velocity variation (4), increasing propulsion because an uninterrupted force application between arms is maintained (27,54). Since the main biomechanical factors affecting swimming are resistance drag and propulsion (69), minimizing imbalances between arms is thought to contribute to optimizing swimming performance (27,54).

Nonetheless, even being a cyclical sport and the importance of the equal use of both limbs is being highlighted, information about the presence and relevance of asymmetry in swimming is inconclusive. Some studies have reported the presence of asymmetry during swimming or in swimmers' body characteristics or performance capabilities (19,52,62,72), while others did not (26,53,57,80). The uncertainty about the relevance of asymmetry in swimming is mainly related to the breathing action, particularly during the front crawl. The action of breathing may cause changes in the stroke's mechanics and coordination (74,80) and in body roll (i.e., the amount of rolling that the body does on the longitudinal axis) (64), which can affect the symmetry of arm action during the stroke (35,74). Moreover, other factors, such as lateral dominance, hand preference, injury history, and anthropometric differences, can also influence the prevalence of asymmetries (48,70) due to the more pronounced use of one limb over the other.

Only a few studies have investigated the influence of asymmetries on swimming performance (27,54,65). Given the possible negative relationship between them, this becomes relevant for practitioners working in the sport. In addition, asymmetries in swimming can be analyzed through in-water or dry-land tests, and the effects of both these asymmetries on swimming performance remain unclear.

Given the current evidence base, some questions remain, such as *"what the studies analyzing asymmetries in swimming are reporting about it?"* and *"do inter-limb asymmetries impact swimming performance?"*. Given the different possible directions a study focusing on asymmetry may take, a more in-depth approach is required to answer each of these questions. Thus, a scoping review was used to systematically explore the available literature to (a) map the studies analyzing bilateral asymmetries in specific (in-water) and non-specific (dry-land) swimming contexts and (b) investigate whether inter-limb asymmetries impact swimming performance.

METHODS

Protocol and registration

The present review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (81). The protocol was registered in Open Science Framework on November 2021 (https://osf.io/46gya).

Eligibility criteria

To be included in the present scoping review, the studies had to: 1) be original investigations evaluating healthy professional or amateur swimmers, 2) investigate the occurrence of bilateral asymmetries in swimming or swimmers, and 3) investigate the relationship between bilateral asymmetries and performance in swimming. Studies were excluded if: 1) they were published in a language other than English, 2) the outcomes of interest (bilateral asymmetry) were not measured or reported, 3) the subjects were swimmers with physical disabilities (e.g., Paralympic swimmers), or 4) they were reviews, or "gray literature" (thesis, dissertations, studies with no peer review). No limitations on swimming technique were imposed; thus, all four techniques (front crawl, backstroke, breaststroke, and butterfly) were included.

Information sources

The searches were completed in PubMed, Scopus, Web of Science, and SPORTDiscus databases. The searches were conducted in July 2021, with a new search performed in August 2021 to update the data. No new studies were included after the second search. The reference list of the included articles was screened for additional studies. The authors were contacted when the manuscript was unavailable on the respective journal website or the ResearchGate portal.

Search

Two researchers carried out the searches independently. The descriptors used were “asymmetries”, “asymmetry”, “symmetry”, “bilateral difference”, “swimming”, “swimmer” and “swimmers”. The final structure of words with the descriptors and operators together was ((asymmetries or asymmetry or symmetry or bilateral deficit or bilateral difference) AND (swimming or swimmer or swimmers)). Each database has filters that allow for limiting the resulting manuscripts. These filters were used to execute some exclusion criteria and avoid the excess of manuscripts unrelated to the search intention. In PubMed, the filters applied were “Species: Human” and “Language: English”. In Web of Science, the filters applied were “Language: English” and “Document Type: Articles”, and then the results were limited to the “Research Area: Sport Science”. In the SPORTDiscus database, the filters applied were “Language: English” and “Document Type: Academic Journal”. Lastly, in Scopus the original structure of words was slightly altered to avoid the excess of results unrelated to the theme. Subsequently, the results were filtered by language and document type and limited to some study areas. The final syntax used in the Scopus database was ((asymmetries OR asymmetry OR symmetry OR bilateral AND deficit OR bilateral AND difference)

AND (swimming OR swimmer OR swimmers) AND NOT (animal OR animals) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SUBJAREA , "MEDI") OR LIMIT-TO (SUBJAREA , "HEAL") OR LIMIT-TO (SUBJAREA , "NEUR") OR LIMIT-TO (SUBJAREA , "PSYC")). Both researchers that conducted the searches used the same structure of words, filters, and limiters, in each database.

Selection of sources of evidence

Two researchers screened and selected the manuscripts resulting from the search. The researchers worked independently, initially evaluating the titles and abstracts of the manuscripts and excluding those that did not fit the inclusion or exclusion criteria. Then, the remaining manuscripts were read in full, and a final selection was made, which was compared between the two researchers. Any inconsistencies in the results were discussed between the researchers, and to resolve any disagreements, a third researcher was consulted when necessary. All the search and selection processes were made manually using Excel and Word software.

Data charting process

Two researchers developed a standardized data charting form to extract the variables of interest of the selected studies. The data charting of the selected studies was made by one researcher and verified by another. The researchers discussed any disagreements, and a third one was consulted if necessary. The data charting was done manually in the Excel software by fully reading the selected manuscripts and transferring interest variables to the form.

Data items

Data regarding the study characteristics (authors, year of publication, title, objectives), participants' characteristics (number of participants, sex, age, competitive level, training experience), tests or variables in which asymmetries were measured, method of data analysis for asymmetry, swimming performance outcome measured, and main results were extracted of the selected studies.

Critical appraisal of individual sources of evidence

The sources of evidence were not critically appraised. However, this is in line with the purpose of a scoping review, which is to provide a narrative or descriptive overview of the evidence on the topic without concern for methodological quality or risk of bias (61).

Synthesis of results

Studies investigating asymmetries in swimming have investigated this concept with various aims. Some studies have explored asymmetries in dry-land tests (16,58,62), others during in-water tests (1,25), and some in both contexts (19,51). Thus, to make the results as clear as possible in this review, they were grouped and presented in three tables (and sections), one for each of the exposed situations. Additionally, a fourth table grouped the results of the studies that investigated the influence of asymmetries on swimming performance.

In addition, asymmetries can be analyzed through different methods, which naturally creates different ways to interpret the data (11). When an equation is used to calculate limb differences, it provides a relative percentage difference (asymmetry % value); or it can simply report the difference between limbs as an absolute value (e.g., 12 cm). On the other hand, when asymmetry is analyzed using a conventional statistical test (e.g., *t*-test), the *p-value* will determine whether the difference between limbs is meaningful. However, the *p*-value is easily affected by sample size, which may require consideration when interpreting results from studies with a small *n*. Thus, to better explore the data, each of the results sections was split into two sub-sections: 1) 'Relative (%) and absolute differences', which summarize the results of the studies that used equations to calculate asymmetries, and 2) 'Between-limb differences', which summarizes the studies that used conventional statistics (e.g., *t*-tests, ANOVA's, etc.) to verify any existing side-to-side differences.

RESULTS

Selection of sources of evidence

Initial searches in the four selected databases resulted in 762 articles. Additionally, six articles were included after manually screening the selected manuscripts' reference list. After removing 124 duplicates, 643 articles were screened by title and abstract. Of these, 572 articles were excluded based on the inclusion/exclusion criteria. Seventy-one articles were selected to be read in full-text, and 11 were excluded for reasons. In the end, 60 articles were eligible for the present scoping review. The details of the charting process, with the specific exclusion reasons, can be seen in Figure 1.

[Figure 1 about here]

Characteristics and results of individual sources of evidence

The characteristics and main data charted of each evidence source are presented in Tables 1, 2, 3, and 4. Table 1 refers to the data about asymmetries measured in dry-land tests, Table 2 concerns asymmetries measured during in-water tests, and Table 3 exposes the studies' results involving asymmetries in both contexts (dry-land and in-water tests. Table 4 presents the results of the studies that investigate the influence of asymmetry on swimming performance.

Synthesis of results

The studies' years of publication ranged from 1978 to 2021. Forty-one studies (68.3%) were published between 2010 and 2021, with 17 (28.3%) of these being published in the last five years (2017 - 2021). According to the first author's main affiliation, most studies are from Australia (14 – 20.3%), followed by Brazil (10 – 16.7%), followed by France and USA with seven studies each (11.7%). Seventeen (28.3%) studies reported some funding (3,6,17,19,23,29,38,49,51-54,57,65,66,76,77).

Regarding participant characteristics, most studies (32 – 53.3%) involved male and female swimmers. Twenty-three studies (38.3%) involved only male swimmers, and just three studies were exclusively female swimmers. Two studies did not specify the sample's gender. The competitive level ranged from club to international levels; however, most studies did not report the competitive level, just mentioning that the participants were competitive swimmers. From those that reported, elite and national levels were the most frequent (approximately 31 studies – 51.7%). The participants ranged from 11 to 61 years, with most being between 15 and 21 years old. Five studies (8.3%) used swimming techniques other than front crawl, and two (3.3%) used other swimming techniques additionally to front crawl. Specifically, three studies used butterfly stroke (51,59,77), two studies used breaststroke (68,77), and four studies used backstroke (7,23,36,77).

Of the 60 included studies, 28 (46.7%) investigated asymmetries in dry-land tests (Table 1), and the main variables in which asymmetries were measured were shoulder range of motion, scapular kinematics (motion, position, and angles), and shoulder and knee strength. Twenty-four studies (40.0%) examined asymmetries during in-water tests (Table 2). The most frequently analyzed variables were propulsive forces, arm coordination, stroke dimensions and phase duration, and hip and shoulder roll. The remaining eight studies (13.3%) explored asymmetries in both tests (Table 3). The analyzed variables were similar to those mentioned before in each context, with the addition of anthropometric variables. For a better understanding and interpretation, the results are explored in the following sections (type of test), sub-sections (asymmetry method of analysis), and Tables. Additionally, Supplemental Digital Content 1 (extra Tables) can be accessed to consult the specific metric values of each limb in each one of the studies and some specific statistical metrics.

Dry-land tests

Relative (%) and absolute differences

Seven of the 28 studies that assessed asymmetries during dry-land tests used relative (%) or absolute between-side differences to analyze asymmetry (Table 1). Four studies calculated asymmetries through percentage differences and verified a range of 1.1-16.6% (18,22,62,76). One study calculated the symmetry index, verifying a percentage of 96.6% or 3.4% asymmetry (29). One study presented the absolute difference between limbs (humeral torsion angle - 6.4°) (87). Finally, one study measured the angle of trunk rotation. It utilized a clinical cut-off point of 5° to determine whether swimmers were "asymmetrical", with females exhibiting a value of 5.3° and males 4.7° (88).

Between-limb differences

Twenty-one studies that measured asymmetries during dry-land tests used statistical tests (e.g., *t*-test, Wilcoxon, ANOVA, Mann-Whitney, or multiple regression) to analyze the between-limbs differences (Table 1). Twelve studies reported no significant side-to-side differences ($p > 0.05$) (6,16,17,32,39,45,47,49,50,72,75,85), while nine showed a significant difference ($p < 0.05$) in at least one tested variable (21,43,56,59,60,63,67,83,84). The specific metrics that presented significant inter-limb differences included: triceps electromyographic activity (reported as a % of maximal voluntary load), shoulder medial and lateral rotation (°), subacromial bursa thickness (mm), scapula-humeral rhythm ratio (°), shoulder extension peak of torque (N.m), shoulder external rotation (°), shoulder isolated and composite internal rotation (°), shoulder total arc of motion (°), power output (W), scapula lateral displacement (cm), scapula retraction peak force (N), and scapula protraction/retraction ratio (N). For further details, see Table 1. Five studies additionally presented the relative or absolute difference between limbs; the range of the percentage differences was 0.9 to 19.7% (58,60,75), and the range of the absolute differences was -15.6 to 21.5 N (79) and -1.3 to 2.1 mm (49). According to the statistical method used, most studies (12 – 57.1%) using dry-land tests did not exhibit any meaningful asymmetries in swimming athletes.

[Table 1 about here]

In-water tests

Relative (%) and absolute differences

Only four of the 24 studies that measured asymmetries during in-water tests did not use statistical tests to determine whether any bilateral differences were present. Two studies utilized relative (%) differences between limbs to calculate asymmetries and found a range value of 2.7-60.0% (38,71). The other two studies presented asymmetries using absolute between-limbs differences, presented through curve graphics (57,77).

Between-limb differences

Eighteen studies utilized inferential statistics (e.g., t-test, Wilcoxon, ANOVA, and/or Chi-square) to determine whether side-to-side differences were significant (1,3,5,24,25,27,33-36,54,59,64-66,73,74,80). They all found significant differences in at least one tested variable ($p < 0.05$). The variables in which asymmetries were found were: hand trajectory (cm), peak and mean force (N), phases duration (%), hip and shoulder roll (°), rate of force development ($N \cdot m \cdot s^{-1}$), stroke width (cm), index of coordination, location of minimum and maximum net forces (%), percentage of overlap (%), duration of underwater stroke (s), minimum and maximum force (absolute – N, and normalized – N/kg), and stroke cycle impulse (N/s) and time (s) (Table 2). Nine studies additionally reported the between-limbs relative (%) difference, finding a range value of -167.3 to 170.9% (3,24,27,54,59,65,66,73,80). Based on the statistical results, asymmetries are present in swimming athletes when measured during in-water tests.

Two studies investigated between-limbs asymmetries through non-inferential statistics. Specifically, one used effect sizes and verified trivial and non-significant differences (7). At the same time, the other utilized the magnitude-based inferences and effect sizes and found small to very large chances of change, in addition to a relative (%) difference of -232.8 to 188.6% (range) (23).

[Table 2 about here]

Dry-land and in-water tests

Relative (%) and absolute differences

Two of the eight studies that investigated asymmetries in dry-land and in-water tests utilized the relative (%) between-limb difference as the analysis method. One study reported an asymmetry range of -24.1 to 17.4% (68). The other used the arbitrary 10%

value as a cut-off to classify the athletes as symmetric or asymmetric during a range of strength assessments using the isokinetic dynamometer. Results verified that 84% of the participants presented asymmetries in strength parameters (30).

Between-limb differences

Six studies analyzed asymmetries through statistical tests (e.g., Wilcoxon, t-test, or ANOVA), and four of them reported significant between-limbs differences ($p < 0.05$) in at least one variable (26,40,51,53). The metrics in which imbalances were seen were: peak force (N) and rate of force development ($N \cdot m \cdot s^{-1}$) (in-water and dry-land), track start performance (s), arm and forearm length (cm), peak and mean velocity (m/s), mean force (N) (in the water), stroke intra-cycle thrust variation (%), knee and shoulder peak of torque (N), wrists and ankles movement patterns (m) (Table 3). Additionally, to the conventional statistics, four studies also reported effect sizes (range: -0.30 to 0.66) (19,51-53), and three also reported relative (%) differences (range: 3.5 to 81.2%) (26,40,52).

[Table 3 about here]

Influence of asymmetry on swimming performance

Of the 60 studies selected to compose the scoping review, only seven (11.7%) investigated the influence of asymmetry on swimming performance (Table 4). Four studies utilized correlational tests to associate the index of asymmetry with the swimming performance outcome. From these, only one verified significant negative correlation (r -0.70 to -0.83) between asymmetries and swimming performance (expressed as take-off velocity from the block) (23). The other three studies did not show significant correlations between asymmetries and swimming velocity, 50m and 25m front crawl time, or 50m and 25m kick time (62,65,66).

Three studies examined the influence of asymmetries on swimming performance by comparing the magnitude of the asymmetries between groups with different performances or comparing the performance between groups with different asymmetry values (> 10 % <). In two studies, no differences were seen in asymmetries values between groups with different 50m front crawl performance or on the technical index (1000 * (world record / swimmer time)^3) between groups with different asymmetry values, suggesting that asymmetries were not detrimental to performance in swimming (54,71). One study found that athletes with better 200m front crawl performance presented less peak and mean force asymmetries. Still, the rate of force development and impulse asymmetries did not differ between groups (27).

[Table 4 about here]

DISCUSSION

The present scoping review aimed to identify the studies analyzing bilateral asymmetries in specific (in-water) and non-specific (dry-land) swimming contexts and investigate inter-limb asymmetries' possible impacts on swimming performance. Sixty studies were selected. Regarding in-water tests (n = 28), asymmetry values ranged from 2.7 to 60.0%, with 18 studies reporting significant between-limbs differences ($p < 0.05$). For dry-land tests (n = 24), asymmetry values ranged reported from 1.1 to 16.6%, with 12 studies showing no significant between-limb differences ($p > 0.05$). The studies that measured asymmetries in both contexts (n = 8) reported asymmetry values from -24.1 to 17.4%, and four found significant differences between body sides ($p < 0.05$). Five of the seven studies reported no meaningful associations with swimming performance when investigating the relationship between asymmetries and swimming performance.

The studies that assessed asymmetry during in-water tests typically presented greater asymmetry values than those with dry-land tests (2.7 to 60.0% vs. 1.1 to 16.6%, respectively), and a superior number of studies found significant between-limb differences when compared to the studies that measured asymmetry during dry-land tests ($n = 18$ vs. 9). In this sense, it seems that asymmetries in swimming athletes are somewhat dependent on the context in which they are measured (i.e., in water or dry-land). Previous studies have shown that the magnitude and direction of asymmetries can change depending on the task being performed (10,14). Although the task-dependence of asymmetries has been shown between different sports (15), the findings of the present study support that within swimming, the notion of task-specificity also exists for asymmetry, thus, likely supporting the use of both in-water and dry-land testing for the assessment of side-to-side differences.

The studies conducted in-water used tethered swimming, predefined distance (e.g., 100 m), or until exhaustion tests and have largely analyzed metrics such as propulsive forces, arm coordination, stroke dimensions, and body alignment. On the other hand, the dry-land tests most often used were strength and flexibility tests. The main outcomes analyzed typically relate to shoulder range of motion, scapular kinematics, and shoulder and knee strength. The primary use of these metrics is not surprising since they are more closely related to performance (66,69,70) and injury risk (79,82) in swimming. Some metrics, such as knee and handgrip strength, and index of coordination, showed consistent results between studies, but most analyzed metrics often varied from study to study. This can be due to multiple factors, such as the swimmer's training level, different metric measurement methods, or even high metric variability. If a metric has high levels of variability (or poor reliability), it is likely harder to detect meaningful differences between test measures or sessions. This occurs because of the large amount of within-group variation that becomes evident in the group, as represented by large standard deviations relative to the mean. According to Excel et al. (31) and Bishop (8), an asymmetry can only be considered 'real' if the values are bigger than the variability (often measured by the coefficient of variation). This assumption helps to differentiate between the signal (asymmetry) and the 'noise' (variability), providing an understanding of whether asymmetry values are meaningful or not (8).

In both contexts (in-water and on dry-land), two main methods of asymmetry analysis were identified. Of the 60 studies, 45 (75%) used conventional statistical analysis (e.g., *t*-test or ANOVA) to determine the between limb differences, with 27 of them finding significant asymmetries ($p < 0.05$). On the other hand, 13 of the 60 studies analyzed asymmetries as a relative (%) difference between limbs, reporting range values of 1.1 to 60.0%. Caution when interpreting the results of both methods should be mentioned. Although statistical tests are a well-established method for assessing differences, it is important to highlight that the answer for the presence of asymmetries lies in the *p-value*, which is influenced by several factors such as sample size and test/metric variability (78). In addition, it provides an absolute cut-off ($p < 0.05$) that seems like a somewhat imperfect system when assessing differences in asymmetry. The relative % difference between body sides has been widely used in the literature (10-12). However, many studies have used the 10% cut-off value as a 'warning signal' about the presence of asymmetries (3,44,71), which also seems to be an arbitrary value to select. It is more common to find meaningful asymmetries when using statistical tests because they use the raw individual limb scores. At the same time, the relative % differences is the creation of one value from two separate sources. Thus, the standard deviation is often larger. When the variability is greater, it reduces the likelihood of finding any meaningful difference. As previously mentioned, alternatives such as using the coefficient of variation to determine meaningful differences, especially on an individual basis, seem more appropriate (9,31).

Additionally, given that asymmetry is a ratio number (i.e., made up of two parts), establishing the direction of an asymmetry (i.e., dominance) provides additional context as to how each limb is performing and can be advantageous (10). Among the studies analyzed in the present review, only one investigated the individual direction of asymmetry and reported the coefficient of variation, using it to interpret the values of asymmetry (62). The authors verified that although the coefficient of variation values were acceptable (< 10%), less than 50% of the tested athletes presented asymmetry scores above the coefficient of variation, indicating no 'real' between-limb differences in over half the sample (62).

Many studies (*n* = 34) found a significant difference between limbs. However, given that swimming is a cyclical sport, the reasoning for these side-to-side differences isn't entirely obvious. One key suggestion, though, is that the breathing action results in asymmetry (24,54,65,74,80). Seifert et al. (73) indicated that the longer time spent inhaling, with the head turned to one side, creates coordination asymmetries due to a propulsive discontinuity between arms. In addition, even if breathing action is disregarded (i.e., no breaths taken during an event), it seems plausible to suggest that the repetition of unilateral breathing action adopted over years of practice and training may generate adaptations in the breathing side that do not occur on the other side (73). Another potential reason for asymmetries in swimming is arm dominance (5,38), whereby one limb may be able to apply more force than the other (5,35,65). Some authors have suggested that the dominant limb is likely responsible for more force production during the stroke, with the non-dominant arm having a greater focus on control and support (25,35,71,74).

Five of the seven studies that investigated the influence of asymmetries on swimming performance did not find meaningful associations (positive or negative) with swimming performance. The reasons why no correlations were seen between asymmetries and swimming performance can be varied. The high variability of asymmetry is almost certainly one reason. In this instance, when aiming to determine the magnitude of a relationship between two variables (i.e., asymmetry and swim time), one data set is likely to be relatively stable (e.g., 50 m swim time). Still, on the other hand, asymmetry, as already discussed, is highly variable. Consequently, the inherent noise of one variable makes it challenging to find any meaningful association between the two. In addition, another potential reason for asymmetries often not being associated with swimming performance is motor control compensatory strategies, where even if a significant asymmetry exists for a given test or metric, the complex interaction of human movement in the water may result in compensations occurring, which enables the athlete to adapt without a reduction in overall performance. This kind of compensation can be seen in the study of Evershed et al. (30), in which 85% of the swimmers presented clinical strength asymmetries, but 50% of these athletes were able to compensate through muscle symmetry and/or an altered kinematic movement pattern, promoting symmetrical hand force generation. Phukan et al. (62) was the only study investigating the asymmetry influence on swimming performance using asymmetries metrics obtained during dry-land tests instead of in-water tests. The authors did not report significant correlations between jump distance or height and performance in 25 / 50 m front crawl or front kick (r range = -0.007 – 0.303; $p > 0.05$) (62). Although jump tests are not swimming-specific, ballistic jump tests are very relevant to swimming performance, especially at the start of the race (86). However, most studies used dry-land tests to investigate asymmetries in swimming, only the study above tried to correlate these inter-limb differences with swimming performance. Therefore, it is impossible to reach a definitive conclusion as to the relevance of dry-land asymmetries on swimming performance.

One final aspect that should be pointed out is that four studies utilized the time of official or simulated swimming competition as the performance outcome. Three studies utilized 50 m time (54,62,66), and one used 200 m time (27). Interestingly, the studies employing 50 m time did not observe any meaningful influence of asymmetries on performance, while the study employing 200 m time did. Despite this very limited body of evidence, it is feasible that between-limb differences are not "given the chance" to negatively impact swimming performance during short duration events (e.g., 50 m) but that they might be for longer duration events (e.g., 200 m). It should be acknowledged that this proposed link between asymmetry and 'fatigue' is largely anecdotal for swimming, although it has been reported in team sports (42). However, given the scarcity of evidence, further research in this space is required in swimming.

This scoping review has some limitations. Firstly, our inclusion criteria required original articles to be published in English, which may have prevented some studies from being considered. However, these criteria resulted in only peer-reviewed studies being included, strengthening the quality of the review. Secondly, the studies in the present review were not critically appraised quantitatively. Although the use of four large databases and our inclusion criteria ensured that only manuscripts that have undergone peer-review were included, some studies may have had greater methodological robustness than others, which may not have been accounted for.

Directions for future research

Although a considerable number of studies regarding asymmetries in swimming can be found in the literature, there are still gaps that should be explored. For example, the relationship between fatigue and asymmetries in swimming is very much under-explored. It would help practitioners determine whether inter-limb differences are exacerbated and from what moment in the race this manifests itself. Such information would help direct targeted training interventions for swimmers when fatigue is likely to be pronounced (i.e., during intense competition weeks).

The causes of the asymmetries also need more research. Although many studies have suggested that respiratory action (74,80) and/or dominance (5,38) are the probable reasons for the appearance of asymmetries in swimming, the causes still need to be completely elucidated. According to Sanders et al. (70), asymmetries can be caused by different factors, such as lateral preference, arm dominance, injuries, environmental factors, genetics, developmental factors, fatigue/overuse, training habits, and breathing action. In this sense, an experimental study that investigates the mechanistic reasoning behind asymmetries involving variables that encompass different environmental and neuro-mechanical aspects would be of great use.

The cause-and-effect relationship between asymmetries and swimming performance also lacks sufficient evidence through studies that use both intervention and control groups. More evidence is needed about the translation of dry-land asymmetries to swimming performance. The only study that made this investigation used lower-limb dry-land tests; thus, future research should explore the relationship between upper-limb asymmetries in dry-land tests and swimming performance. This seems especially relevant given the magnitude of upper body contribution to force production in the water (55).

Another aspect that future research can explore better is asymmetries in swimming techniques other than front crawl, even more so when it is suggested that asymmetries associated with years of unilateral breathing during front crawl may generate different strength adaptations between arms (54,73). This could reflect in other swimming techniques where both limbs are required equally and simultaneously (e.g., breaststroke and butterfly stroke) and can be explored. Also, the experience levels of swimmers might be another factor influencing the level of asymmetry and its potential effects on performance. Although some research has been conducted comparing asymmetries between different performance levels in swimming (25,27,71), more studies are needed to reach a clear conclusion.

Finally, future research should seek methods of analyzing asymmetry capable of elucidating meaningful limb differences on an individual level. Due to the variable nature of asymmetry, differentiating between the signal and the noise is critical. Furthermore, test protocols should align with the sport or events demands, where possible. For example, during the start in swimming, the track start (staggered stance) is more usual than a symmetrical bilateral start off the blocks. Thus, future research may investigate jump performance in a staggered stance (similar to the start), which may provide some useful understanding of sport-specific ballistic force production for swimmers.

CONCLUSION

From the cumulative body of literature analyzed in the present study, asymmetries in swimming are more evident during in-water tests than during dry-land tests, with a higher range of asymmetry values and a higher number of studies verifying significant between-limb differences. Various methods of asymmetry analysis have been used; thus, some caution is suggested when interpreting the results. Few studies investigated the link between asymmetries and swimming performance, with most reporting no meaningful relationships. Future research should focus on individual data analysis to determine whether meaningful changes in asymmetry correspond to meaningful improvements in race times.

References

1. Aujouannet YA, Rouard AH, Bonifazi M. Effects of fatigue on the kinematic hand’s symmetry in freestyle. *Rev Port Ciênc Desporto* 6: 24-26, 2006.

2. Bailey C, Sato K, Alexander R, Chiang C, Stone MH. Isometric force production symmetry and jumping performance in collegiate athletes. *J Trainology* 2: 1-5, 2013.

3. Barbosa AC, Andries Júnior O. Effects of different hand paddle sizes on bilateral propulsive force difference in front crawl swimming. *Serb J Sports Sci* 5: 91-97, 2011.

4. Barbosa TM, Bragada JA, Reis VM, Marinho DA, Carvalho C, Silva AJ. Energetics and biomechanics as determining factors of swimming performance: updating the state of the art. *J Sci Med Sport* 13: 262–269, 2010.

5. Barden JM, Kell RT, Kobsar D. The effect of critical speed and exercise intensity on stroke phase duration and bilateral asymmetry in 200-m front crawl swimming. *J Sports Sci* 29: 517–526, 2011.

6. Beach ML, Whitney SL, Dickoff-Hoffman S. Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. *J Orthop Sports Phys Ther* 16: 262–268, 1992.

7. Becker T, Havriluk R. Bilateral and anterior-posterior muscular imbalances in swimmers. *Rev Port Ciênc Desporto* 6: 327-328, 2006.

8. Bishop C. Interlimb Asymmetries: are thresholds a usable concept? *Strength Cond J* 43: 32-36, 2021.

9. Bishop C, Lake J, Loturco I, et al. Interlimb Asymmetries: the need for an individual approach to data analysis. *J Strength Cond Res* 35: 695–701, 2021.

10. Bishop C, Pereira LA, Reis VP, et al. Comparing the magnitude and direction of asymmetry during the squat, countermovement and drop jump tests in elite youth female soccer players. *J Sports Sci* 38: 1296–1303, 2020.

11. Bishop C, Read P, Chavda S, Turner A. Asymmetries of the lower limb: the calculation conundrum in strength training and conditioning. *Strength Cond J* 38: 27-32, 2016.

12. Bishop C, Read P, Lake J, Chavda S, Turner A. Interlimb asymmetries: Understanding how to calculate differences from bilateral and unilateral tests. *Strength Cond J* 40: 1–6, 2018.

13. Bishop C, Read P, McCubbine J, Turner A. Vertical and horizontal asymmetries are related to slower sprinting and jump performance in elite youth female soccer players. *J Strength Cond Res* 35: 56-65, 2021.

14. Bishop C, Turner A, Jarvis P, Chavda S, Read P. Considerations for selecting field-based strength and power fitness tests to measure asymmetries. *J Strength Cond Res* 31: 2635–2644, 2017.

15. Bishop C, Turner A, Read P. Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *J Sports Sci* 36: 1135-1144, 2018.

16. Blache Y, Gillet B, Selin J, Sevrez V, Rogowski I. Scapular kinematics during scaption in competitive swimmers. *Eur J Sport Sci* 18: 659-666, 2018.

17. Boettcher C, Halaki M, Holt K, Ginn KA. Is the normal shoulder rotation strength ratio altered in elite swimmers? *Med Sci Sports Exerc* 52: 680–684, 2020.

18. Butler R, Arms J, Reiman M, et al. Sex differences in dynamic closed kinetic chain upper quarter function in collegiate swimmers. *J Athl Train* 49: 442–446, 2014.

19. Carvalho DD, Soares S, Zacca R, et al. In-water and on-land swimmers' symmetry and force production. *Int J Environ Res Public Health* 16: 5018-5026, 2019.

20. Chalmers S, Fuller JT, Debenedictis TA, et al. Asymmetry during preseason Functional Movement Screen testing is associated with injury during a junior Australian football season. *J Sci Med Sport* 20: 653–657, 2017.

21. Couanis G, Breidahl W, Burnham S. The relationship between subacromial bursa thickness on ultrasound and shoulder pain in open water endurance swimmers over time. *J Sci Med Sport* 18: 373–377, 2015.

22. Dalamitros AA, Manou V, Christoulas K, Kellis S. Knee muscles isokinetic evaluation after a six-month regular combined swim and dry-land strength training period in adolescent competitive swimmers. *J Hum Kinet* 49: 195–200, 2015.

23. de Jesus K, de Jesus K, Gonçalves P, et al. Lateral kinetic proficiency and asymmetry in backstroke start performed with horizontal and vertical handgrips. *Sports Biomech* 20: 71–85, 2021.

24. Dieguez, OV, Barden, JM. Body roll differences in freestyle swimming between swimmers with and without shoulder pain. *Sports Biomech*, 2020. [e-pub ahead of print].

25. dos Santos KB, Bento P, Payton C, Rodacki A. Kinematic parameters after repeated swimming efforts in higher and lower proficiency swimmers and para-swimmers. *Res Q Exerc Sport* 91: 574–582, 2020.

26. dos Santos KB, Bento P, Pereira G, Payton C, Rodacki A. Front crawl swimming performance and bi-lateral force asymmetry during land-based and tethered swimming tests. *J Sports Sci Med* 16: 574–580, 2017.

27. dos Santos KB, Pereira G, Papoti M, Bento PC, Rodacki A. Propulsive force asymmetry during tethered-swimming. *Int J Sports Med* 34: 606–611, 2013.

28. Dos'Santos T, Thomas C, Comfort P, Jones PA. Comparison of change of direction speed performance and asymmetries between team-sport athletes: application of change of direction deficit. *Sports* 6: 174-189, 2018.

29. Engstrom CM, Walker DG, Kippers V, Mehnert AJ. Quadratus lumborum asymmetry and L4 pars injury in fast bowlers: a prospective MR study. *Med Sci Sports Exerc* 39: 910–917, 2007.

30. Evershed J, Burkett B, Mellifont R. Musculoskeletal screening to detect asymmetry in swimming. *Phys Ther Sport* 15: 33–38, 2014.

31. Exell TA, Irwin G, Gittoes MJ, Kerwin DG. Implications of intra-limb variability on asymmetry analyses. *J Sports Sci* 30: 403-409, 2012.

32. Falk B, Bronshtein Z, Zigel L, Constantini N, Eliakim A. Higher tibial quantitative ultrasound in young female swimmers. *Br J Sports Med* 38: 461–465, 2004.

33. Formosa DP, Mason B, Burkett B. The force-time profile of elite front crawl swimmers. *J Sports Sci* 29: 811–819, 2011.

34. Formosa DP, Sayers MG, Burkett B. Front-crawl stroke-coordination and symmetry: a comparison between timing and net drag force protocols. *J Sports Sci* 31: 759–766, 2013.

35. Formosa DP, Sayers MG, Burkett B. Quantifying stroke coordination during the breathing action in front-crawl swimming using an instantaneous net drag force profile. *J Sports Sci* 32: 1729–1737, 2014.

36. Formosa DP, Sayers MG, Burkett B. Stroke-coordination and symmetry of elite backstroke swimmers using a comparison between net drag force and timing protocols. *J Sports Sci* 32: 220–228, 2014.

37. Fort-Vanmeerhaeghe A, Milà-Villarroel R, Pujol-Marzo M, Arboix-Alió J, Bishop, C. Higher vertical jumping asymmetries and lower physical performance are indicators of increased injury incidence in youth team-sport athletes. *J Strength Cond Res*, 2020. [e-pub ahead of print].

38. Guignard B, Rouard A, Chollet D, et al. Upper to lower limb coordination dynamics in swimming depending on swimming speed and aquatic environment manipulations. *Motor Control* 23: 418–442, 2019.

39. Hanson C, Lofthus GK. Effects of fatigue and laterality on fractionated reaction time. *J Mot Behav* 10: 177–184, 1978.

40. Hardt J, Benjanuvatra N, Blanksby B. Do footedness and strength asymmetry relate to the dominant stance in swimming track start? *J Sports Sci* 27: 1221–1227, 2009.

41. Hart NH, Nimphius S, Weber J, et al. Musculoskeletal asymmetry in football athletes: A product of limb function over time. *Med Sci Sports Exerc* 48: 1379-1387, 2016.

42. Heil J, Loffing F, Büsch D. The influence of exercise-induced fatigue on inter-limb asymmetries: a systematic review. *Sports Med* 6: 39, 2020.

43. Hosseinimehr SH, Anbarian M. The effects of activities related to sports on scapular resting position and scapulohumeral rhythm ratio. *Sport Sci Health* 16: 713–717, 2020.

44. Impellizzeri FM, Rampinini E, Maffiuletti N, Marcora SM. A vertical jump force test for assessing bilateral strength asymmetry in athletes. *Med Sci Sports Exerc* 39: 2044–2050, 2007.

45. Leroy D, Polin D, Tourny-Chollet C, Weber J. Spatial and temporal gait variable differences between basketball, swimming and soccer players. *Int J Sports Med* 21: 158–162, 2000.

46. Madruga-Parera M, Bishop C, Beato M, Fort-Vanmeerhaeghe A, Gonzalo-Skok O, Romero-Rodríguez D. Relationship between interlimb asymmetries and speed and change of direction speed in youth handball players. *J Strength Cond Res* 35: 3482-3490, 2021.

47. Magnusson SP, Constantini NW, McHugh MP, Gleim GW. Strength profiles and performance in Masters' level swimmers. *Am J Sports Med* 23: 626–631, 1995.

48. Maloney SJ. The relationship between asymmetry and athletic performance: a critical review. *J Strength Cond Res* 33: 2579-2593, 2018.

49. McKenna L, Straker L, Smith A, Cunningham J. Differences in scapular and humeral head position between swimmers and non-swimmers. *Scand J Med Sci Sports* 21: 206–214, 2011.

50. McLaine SJ, Ginn KA, Fell JW, Bird ML. Scapular upward rotation position is symmetrical in swimmers without current shoulder pain. *Phys Ther Sport* 29: 9–13, 2018.

51. Morais JE, Barbosa TM, Lopes VP, Marques MC, Marinho DA. Propulsive force of upper limbs and its relationship to swim velocity in the butterfly stroke. *Int J Sports Med* 42: 1105–1112, 2021.

52. Morais JE, Forte P, Nevill AM, Barbosa TM, Marinho DA. Upper-limb kinematics and kinetics imbalances in the determinants of front-crawl swimming at maximal speed in young international level swimmers. *Sci Rep* 10, 2020.

53. Morais JE, Marques MC, Rodríguez-Rosell D, Barbosa TM, Marinho DA. Relationship between thrust, anthropometrics, and dry-land strength in a national junior swimming team. *Physician Sportsmed* 48: 304–311, 2020.

54. Morouço PG, Marinho DA, Fernandes RJ, Marques MC. Quantification of upper limb kinetic asymmetries in front crawl swimming. *Hum Mov Sci* 40: 185–192, 2015.

55. Morouço PG, Marinho DA, Izquierdo M, Neiva H, Marques MC. Relative contribution of arms and legs in 30 s fully tethered front crawl swimming. *Biomed Res Int* 2015: 1-6, 2015.

56. Nazário-de-Rezende F, Sousa GC, Haddad EG, et al. Electromyographic study of the deltoid, pectoralis major and triceps brachii muscles in swimmers during bilateral contractions performed in multi-joint exercise with different loads. *Rev Bras Med Esporte* 18: 100–104, 2012.

57. Nikodelis T, Kollias I, Hatzitaki V. Bilateral inter-arm coordination in freestyle swimming: effect of skill level and swimming speed. *J Sports Sci* 23: 737–745, 2005.

58. Pereira FR, Gonçalves GGP, Reis DR, et al. Comparison of glenohumeral joint rotation range of motion in young athletes. *Rev Bras Med Esporte* 25: 53–57, 2019.

59. Pereira GS, Schut GR, Ruschel C, Roesler H, Pereira SM. Propulsive force symmetry generated during butterfly swimming. *Rev Bras Cineantropometria Desempenho Hum* 17: 704-716, 2015.

60. Perrin DH, Robertson RJ, Ray RL. Bilateral lsokinetic peak torque, torque acceleration energy, power, and work relationships in athletes and nonathletes. *J Orthop Sports Phys Ther* 9: 184–189, 1987.

61. Peters MDJ, Godfrey CM, McInerney P, et al. (2015). *The Joanna Briggs Institute Reviewers' Manual 2015: Methodology for JBI scoping reviews*. Adelaide, South Australia: The Joanna Briggs Institute, 2015.

62. Phukan MI, Thapa RK, Kumar G, et al. Inter-limb jump asymmetries and their association with sport-specific performance in young male and female swimmers. *Int J Environ Res Public Health* 18: 7324-7333, 2021.

63. Potts AD, Charlton JE, Smith HM. Bilateral arm power imbalance in swim bench exercise to exhaustion. *J Sports Sci* 20: 975–979, 2002.

64. Psycharakis SG, McCabe C. Shoulder and hip roll differences between breathing and non-breathing conditions in front crawl swimming. *J Biomech* 44: 1752–1756, 2011.

65. Psycharakis SG, Sanders RH. Shoulder and hip roll changes during 200-m front crawl swimming. *Med Sci Sports Exerc* 40: 2129–2136, 2008.

66. Psycharakis SG, Soultanakis H, González Ravé JM., Paradisis GP. Force production during maximal front crawl tethered swimming: exploring bilateral asymmetries and differences between breathing and non-breathing conditions. *Sports Biomechanics*, 2021. [e-pub ahead of print].

67. Riemann BL, Witt J, Davies GJ. Glenohumeral joint rotation range of motion in competitive swimmers. *J Sports Sci* 29: 1191–1199, 2011.

68. Sanders RH, Fairweather MM, Alcock A, McCabe CB. An approach to identifying the effect of technique asymmetries on body alignment in swimming exemplified by a case study of a breaststroke swimmer. *J Sports Sci Med* 14: 304–314, 2015.

69. Sanders RH. How do asymmetries affect swimming performance? *J Swim Res* 21, 2013.

70. Sanders RH, Thow J, Fairweather M. Asymmetries in swimming: where do they come from? *J Swim Res* 18:1-6, 2011.

71. Santos KB, Bento P, Payton C, Rodacki A. Symmetry in the front crawl stroke of different skill level of able-bodied and disabled swimmers. *PloS One* 15, 2020.

72. Secchi LL, Muratt MD, Ciolac EG, Greve J. Knee muscles isokinetic evaluation in short distance elite swimmers: A comparison between symmetric and asymmetric swimming styles. *Isokinet Exerc Sci* 19: 261–264, 2011.

73. Seifert L, Chehensse A, Tourny-Chollet C, Lemaitre F, Chollet D. Effect of breathing pattern on arm coordination symmetry in front crawl. *J Strength Cond Res* 22: 1670–1676, 2008.

74. Seifert L, Chollet D, Allard P. Arm coordination symmetry and breathing effect in front crawl. *Hum Mov Sci* 24: 234–256, 2005.

75. Sevimli D. Correlations among handedness, handgrip strength and front crawl swimming performance in adolescents. *Kinesiol Slov* 22: 23–30, 2016.

76. Shaw CN, Stock JT. Habitual throwing and swimming correspond with upper limb diaphyseal strength and shape in modern human athletes. *Am J Phys Anthropol* 140: 160–172, 2009.

77. Silvatti AP, Cerveri P, Telles T, et al. Quantitative underwater 3D motion analysis using submerged video cameras: accuracy analysis and trajectory reconstruction. *Comput Methods Biomech Biomed Engin* 16: 1240–1248, 2013.

78. Thiese MS, Ronna B, Ott U. P value interpretations and considerations. *J Thorac Dis* 8: E928–E931, 2016.

79. Tooth C, Gofflot A, Schwartz C, et al. Risk factors of overuse shoulder injuries in overhead athletes: a systematic review. *Sports Health* 12: 478–487, 2020.

80. Tourny-Chollet C, Seifert L, Chollet D. Effect of force symmetry on coordination in crawl. *Int. J. Sports Med* 30: 182–187, 2009.

81. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and Explanation. *Ann Intern Med* 169: 467-473, 2018.

82. Trinidad A, González-Garcia H, López-Valenciano A. An updated review of the epidemiology of swimming injuries. *PM & R* 13: 1005–1020, 2021.

83. Van de Velde A, de Mey K, Maenhout A, Calders P, Cools AM. Influence of a single swim training on the scapular position and isometric muscle strength in young swimmers. *Int J Aquat Res Educ* 4: 257–268, 2010.

84. Van de Velde A, de Mey K, Maenhout A, Calders P, Cools AM. Scapular-muscle performance: two training programs in adolescent swimmers. *J Athl Train* 46: 160–169, 2011.

85. Wadsworth DJ, Bullock-Saxton JE. Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. *Int J Sports Med* 18: 618–624, 1997.

86. West DJ, Owen NJ, Cunningham DJ, Cook CJ, Kilduff LP. Strength and power predictors of swimming starts in international sprint swimmers. *J Strength Cond Res* 25: 950-955, 2011.

87. Whiteley RJ, Ginn KA, Nicholson LL, Adams RD. Sports participation and humeral torsion. *J Orthop Sports Phys Ther* 39: 256–263, 2009.

88. Zaina F, Donzelli S, Lusini M, Minnella S, Negrini S. Swimming and spinal deformities: a cross-sectional study. *J Pediatr* 166: 163–167, 2015.

Figure Caption

Figure 1. Flow diagram of the charting process, based on PRISMA-ScR recommendations.

Table Captions

Table 1. Summary of studies that measured asymmetries in swimming athletes during dry-land tests.

R: right, L: left, ≠: difference, D: dominant, ND: non-dominant, SLCMJ: single-leg countermovement jump, SLHJ: single-leg horizontal jump, P: preferred side, NP: non-preferred side.

Table 2. Summary of studies that measured asymmetries in swimming athletes during in-water tests.

SI: symmetry index, R: right, L: left, S: stronger, W: weaker, ≠: difference, P: preferred, NP: non-preferred, MBI: magnitude based inference, ASI: asymmetry index, B: breathing, NB: non-breathing, D: dominant, ND: non-dominant.

Table 3. Summary of studies that measured asymmetries in swimming athletes during dry-land and in-water tests.

SI: symmetry index, P: preferred, NP: non-preferred, S: strong side, W: weak side, R: right, L: left, D: dominant, ND: non-dominant.

Table 4. Studies investigating the influence of asymmetries on swimming performance.

≠: difference(s), SLCMJ: single-leg countermovement jump, SLSLJ: single-leg standing long jump.

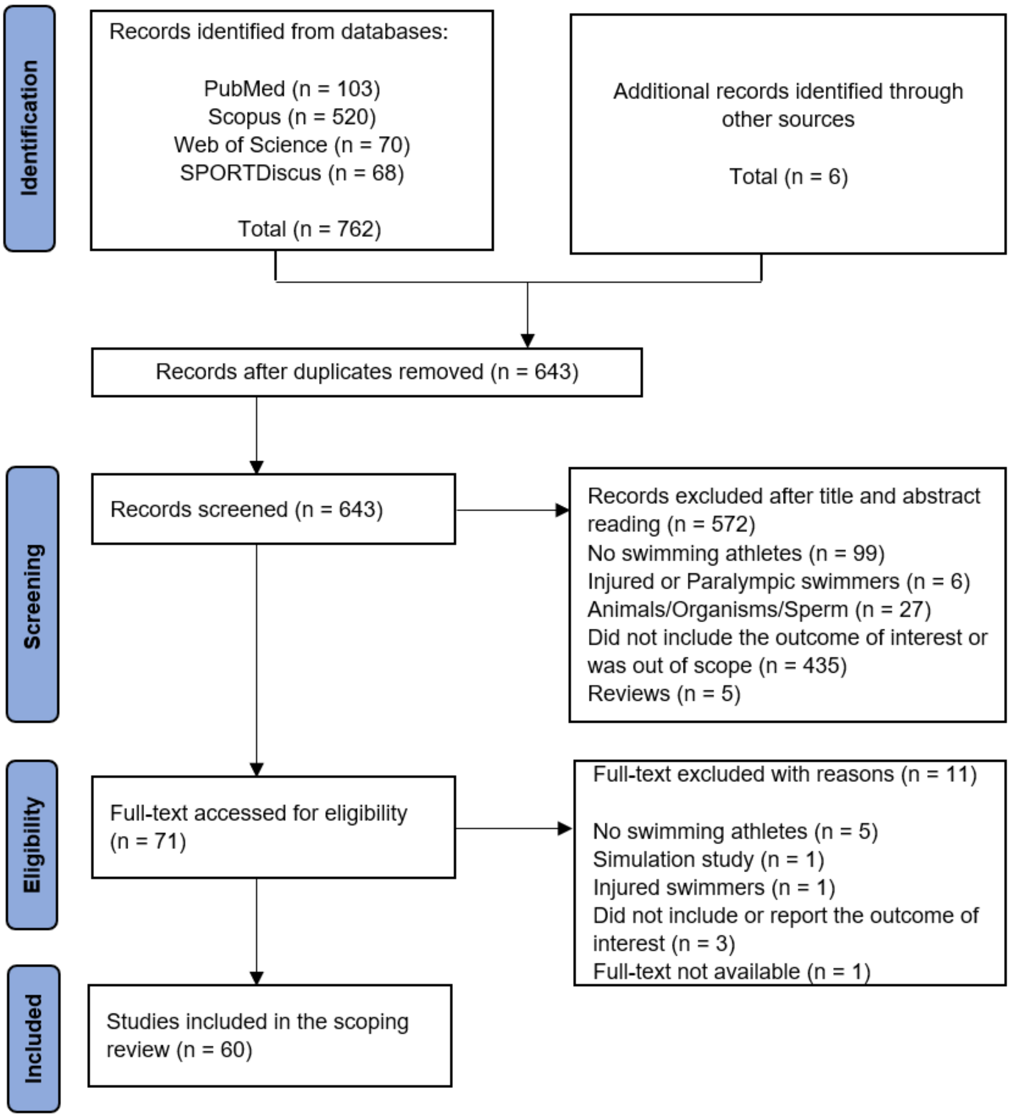
Identification
Records identified from databases:
PubMed (n = 103)
Scopus (n = 520)
Web of Science (n = 70)
SPORTDiscus (n = 68)
Total (n = 762)
Additional records identified through other sources
Total (n = 6)
Records after duplicates removed (n = 643)
Screening
Records screened (n = 643)
Records excluded after title and abstract reading (n = 572)
No swimming athletes (n = 99)
Injured or Paralympic swimmers (n = 6)
Animals/Organisms/Sperm (n = 27)
Did not include the outcome of interest or was out of scope (n = 435)
Reviews (n = 5)
Eligibility
Full-text accessed for eligibility (n = 71)
Full-text excluded with reasons (n = 11)
No swimming athletes (n = 5)
Simulation study (n = 1)
Injured swimmers (n = 1)
Did not include or report the outcome of interest (n = 3)
Full-text not available (n = 1)
Included
Studies included in the scoping review (n = 60)

Table 1. Summary of studies that measured asymmetries in swimming athletes during dry-land tests.

Study	Participants characteristics	Asymmetry variable(s) measured	Asymmetry method of analysis	Asymmetries main results
Beach et al. (6), USA	32 swimmers (8 male; 24 female); age: 19.0; national level	Shoulder range of motion (ROM); shoulder strength ratios of external rotation (ER) / internal rotation (IR) and abduction (ABD) / adduction (ADD); shoulder endurance ratio of ER, IR, ABD, and ADD	Paired t-test (R - L)	No ≠ between sides in ROM or shoulder mean percent ratios ($p > 0.05$)
Blache et al. (16), France	31 male swimmers (11 adolescent elite; age: 17.0 ± 1.0; 10 adult elite; age: 21.9 ± 2.2; 10 club-level adult; age: 20.8 ± 4.4)	Scapular kinematics	One-way ANOVA + graphic data presentation; (D - ND)	No side-to-side ≠ in scapular elevation/depression, IR/ER, protraction/retraction, anterior/posterior tilt, or downward/upward rotation, for all swimmers groups ($p > 0.05$)
Boettcher et al. (17), AU	68 elite swimmers (40 male; 28 female); age: 19.9 ± 3.2	Shoulder IR and ER strength; Shoulder IR/ER ratio	Mixed-model analysis (D - ND)	No ≠ between sides for shoulder rotation strength ($p = 0.547$) or shoulder ratio ($p = 0.665$)
Butler et al. (18), USA	97 swimmers (43 male; age: 19.3 ± 1.2; 54 female; age: 19.1 ± 0.7); national level	Y balance test performance for inferiolateral, superolatural, and medial directions (reach asymmetry); and sum across directions (sum asymmetry)	Percentage value differences between sides (R –L)	Asymmetries (cm) (male – female): Inferolateral: 4.1 ± 3.5% - 4.1 ± 4.4% Superolateral: 4.7 ± 4.1% - 4.5 ± 3.7% Medial: 3.3 ± 2.6% - 3.4 ± 2.8% Sum: 12.2 ± 5.4% - 12.0 ± 7.9%
Couasis et al. (21), AU	20 marathon swimmers (15 male; 5 female); age: 37.3 ± 9.7; elite and amateur levels	Subacromial bursa thickness (SAB)	Mixed-model ANOVA (R – L and With pain – Without pain)	No ≠ between sides before the race ($p > 0.05$). SAB of shoulders with pain were > than shoulders without pain in post-race ($p = 0.03$)
Dalamitros et al. (22), Greece	11 male swimmers; age: 14.8 ± 0.4; state and national level	Knee flexion (FLE) and extension (EXT) peak of torque (PT)	Percentage deficit (R – L)	Asymmetries before vs. after a 6-month training: FLE: 2.9 ± 13.8 % vs. 1.3 ± 10.3 %; EXT: 2.6 ± 8.8 % vs. 1.1 ± 10.6 %
Engstrom et al. (29), AU	20 male swimmers; age:13 – 17; (control group)	Quadratus lumborum muscle volume	Asymmetry = [(D/ND) * 100]	Asymmetry: 96.6 ± 5.0 %
Falk et al. (32), Israel	61 female swimmers; age: 15.9 ± 4.9; regional level	Radial and tibial speed of sound	Independent t-test (D – ND)	No ≠ between sides (p > 0 .05)
Hanson & Lofthus (39), USA	12 competitive female swimmers; age: 19.5 ± 1.1	Handgrip strength and reaction time components (total, premotor, and motor time)	One-way ANOVA (D – ND)	No ≠ between limbs ($p > 0.05$). No alterations under fatigue conditions ($p > 0.05$)

Hosseinimehr & Anbarian (43), Iran	15 male swimmers; age: 19.9 ± 1.1; college level	Scapular up/downward rotation (resting position); Scapulohumeral rhythm ratio	ANOVA (D – ND)	No ≠ between sides for scapular resting position ($p > 0.05$). Less scapulohumeral rhythm ratio for dominant side ($p < 0.01$)
Leroy et al. (45), France	10 male swimmers; age: 20.0 ± 3.6; national level	Stride length, step length, and cycle, stance, swing, double support, early swing phase, and late swing phase durations	Paired t-test (R – L)	No significant ≠ between sides for any variable ($p > 0.05$)
Magnusson et al. (47), USA	24 swimmers (13 male; age: 31.2 ± 1,3; 11 female; age: 29.4 ± 1,3); state and national level	Shoulder IR, ER, ABD, and supraspinatus muscle strength; Knee EXT and FLE strength; Shoulder IR and ER ROM	Paired t-test (R – L)	Symmetrical shoulder and knee strength, and shoulder ROM ($p > 0.05$)
McKenna et al. (49), AU	46 swimmers (16 male; 30 female); age: 14.6 ±1.5; elite level	Superior Kibler, Inferior Kibler and humeral head position	Multiple Regression (D – ND)	No ≠ between sides for Superior Kibler (0.5mm, $p = 0.71$), Inferior Kibler (2.1mm, $p = 0.06$), or humeral head position (-1.3mm, $p = 0.058$)
McLaine et al. (50), AU	85 swimmers (27 history of pain (age: 17.0) and 58 without history of pain (age: 15.0)); club level	Scapular upward rotation (90° and 140° of shoulder ABD)	Paired t-test (D – ND; With history of pain – without history of pain)	No side-to-side ≠ between shoulders without history of pain (90° $p = 0.16$; 140° $p = 0.08$) or with history of pain (90° $p = 0.07$; 140° $p = 0.09$)
Nazário-de-Rezende et al. (56), Brazil	11 male swimmers; age: 19.0 ± 4.0	Electromyographyc activity of deltoid medialis, pectoralis major and triceps brachii muscles at 40% and 80% maximum voluntary load	Wilcoxon and t-tests (D – ND)	≠ between D and ND limbs only for triceps brachii in 80% maximum voluntary load (283 ± 96 vs. 230 ± 62, $p = 0.016$)
Pereira et al. (58), Brazil	158 swimmers (male and female); age: 11 - 19	Shoulder medial and lateral shoulder ROM	Paired t-test (R – L)	Medial rotation asymmetry: 19.7 ± 14.7%, favoring left side ($p < 0.01$); Lateral rotation asymmetry: 12.6 ± 12.3%, favoring right side ($p < 0.01$)
Perrin et al. (60), USA	15 male swimmers; age: 18-27 (mean: 19); intercollegiate level	Knee EXT and FLE, shoulder EXT, FLE, IR and ER PT (60-180°/s). Torque acceleration energy, average power, and total work (180°/s)	Two-way ANOVA (R – L)	Asymmetries values within 5%. Significant ≠ (> R) only for shoulder EXT PT (60°s and 180°s) ($p < 0.05$)
Phukan et al. (62), India	38 swimmers (19 male; 19 female); age: 12.3 ± 1.2; regional and national level	Jump height (${}_{SL}$CMJ); Jump distance (${}_{SL}$HJ)	Asymmetry = [(D/ND) * 100]	Asymmetries: Male: ${}_{SL}$CMJ - 7.1 ± 4.9 %; ${}_{SL}$HJ - 6.0 ± 5.6 %; Female: ${}_{SL}$CMJ - 9.9 ± 5.5%; ${}_{SL}$HJ - 5.4 ± 3.1%; Total: ${}_{SL}$CMJ - 8.5 ± 5.3%; ${}_{SL}$HJ - 5.7 ± 4.5%
Potts et al. (63), UK	10 competitive swimmers (5 males, 5 females); age: 20.5 ± 2.3	Power output during simulated swimming exercise to exhaustion (2min)	Two-way ANOVA; t-test (R –L)	External power output > L arm ($p < 0.01$) during the test
Riemann et al. (67), USA	144 competitive swimmers (youth, high school, college, and master; male and female); age:12-61	Shoulder ER, isolated IR and composite IR, and total arc of motion	ANOVA with repeated measures (D – ND)	ER: > D for male and female high school and collegiate, youth female, master male ($p < 0.01$). Isolated IR, composite IR, and total arc of motion: > ND ($p < 0.01$)

Secchi et al. (72), Brazil	19 swimmers; simultaneous style (6 male, 1 female; age: 23.3 ± 5.6); alternated style (10 male, 2 female; age: 20.1 ± 2.8); international and national levels	PT (60°/s), total work (300°/s), and work fatigue (300°/s) of knee EXT and FLE; Agonist/antagonist ratio (PT - 60°s)	Two-way ANOVA (R – L)	No significant ≠ between legs for any tested variable ($p > 0.05$)
Sevimli (75), Turkey	41 swimmers (22 male; age: 15.8 ± 1.3; 19 female; age: 15.9 ± 1.0); national level	Handgrip strength	Percentage difference (R – L) + Mann-Whitney	Asymmetry values: Left handed males 3.9% ($p = 0.80$) Right handed males 0.9% ($p = 0.91$) Left handed females 15.7% ($p = 0.14$) Right handed females 8.9% ($p = 0.22$)
Shaw & Stock (76), UK	15 male competitive swimmers; age: 21.9 ± 2.5	Cross-sectional diaphyseal properties of humeral and ulnae (rigidity and shape)	Asymmetry = [(D/ND)/D * 100]	Asymmetries ranged from 2.3 to 10.6% in humeral variables, and from 2.1 to 16.6% in ulnae variables
Van de Velde et al. (83), Belgium	30 swimmers (15 male; 15 female); age: 15.6 ± 1.6; regional level	Scapula lateral displacement (3 positions), shrug and push forces, and strength ratio	Two-way ANOVA (D – ND) + absolute difference	> scapula lateral displacement on the D side in all 3 positions (1st $p = 0.037$, 2nd $p = 0.011$, 3rd $p = 0.005$). No significant strength ≠ between sides (pretest: shrug: $p = 0.079$, push: $p = 0.797$ and ratio: $p = 0.491$; posttest: shrug: $p = 0.399$, push: $p = 0.600$ and ratio: $p = 0.853$). Different shrug asymmetry value pre-post test (21.48 vs. -15.56 N, $p < 0.01$)
Van de Velde et al. (84), Belgium	18 competitive swimmers (7 male; 11 female); age: 14.7 ± 1.3	Scapular protraction and retraction peak force (PF), fatigue index (FI) and protraction/retraction (P/R) strength ratio, pre and post training	Three-way ANOVA with repeated measures (D – ND)	No side-to-side ≠ for protraction PF or FI ($p > 0.05$). Side-to-side ≠ for retraction PF (pre 200.4 ± 81.5 vs. 137.5 ± 66.4, $p = 0.03$; post 221.9 ± 59.0 vs. 249.5 ± 67.9, $p = 0.05$) and P/R (pre 1.1 ± 0.2 vs. 1.5 ± 0.3, $p < 0.01$; post 1.1 ± 0.3 vs. 0.9 ± 0.2, $p = 0.24$)
Wadsworth & Bullock-Saxton (85), AU	9 competitive swimmers; age: 19.3 (control group)	Upper trapezius, lower trapezius, and serratus anterior EMG	ANOVA (P – NP)	No ≠ between sides (p > 0.05)
Whiteley et al. (87), AU	29 high-level swimmers (10 male; 19 female); age: 15.9 ± 1.6	Humeral torsion angle	Absolute difference (D – ND)	6.4 ± 9.9°
Zaina et al. (88), Italy	112 competitive swimmers (50 male; 62 female); age: 12.5	Angle of trunk rotation	Mean + clinical cutoff (5°) + odds ratio	Absolute values: male 4.7 ± 2.3 °, female 5.3 ± 2.7°. Swimming was associated with an ↑ risk of trunk asymmetries (OR 1.68, $p < 0.05$), with the highest risk in females

R: right, L: left, ≠: difference, D: dominant, ND: non-dominant, $_{SL}$CMJ: single-leg countermovement jump, $_{SL}$HJ: single-leg horizontal jump, P: preferred side, NP: non-preferred side.

Table 2. Summary of studies that measured asymmetries in swimming athletes during in-water tests.

Study	Participants characteristics	Asymmetry variable(s) measured	Asymmetry method of analysis	Asymmetries main results
Aujouannetl et al. (1), France	8 male swimmers; age: 22.5 ± 2.3; international level	Hand trajectories (temporal and spatial coordinates of each point of swimming)	SI = [R – L / 0.5 (R + L)] * 100; + Wilcoxon	Spatial symmetry ($p > 0.05$) and the temporal asymmetry ($p < 0.05$) were maintained after fatigue
Barbosa & Andries Jr. (3), Brazil	14 male swimmers; age: 20.0 ± 3.7; national level	Peak force (PF) using four sizes of hand paddles (small, medium, large, extra-large) and none (free)	Relative (%) difference; Independent t-test; (S – W)	There was ≠ between the S and W strokes in all conditions ($p < 0.05$). No ≠ between conditions ($p > 0.05$). Mean asymmetry: free (19.9 %); small (17.3 %); medium (14.2 %); large (14.1 %); extra-large (14.4 %)
Barden et al. (5), Canada	8 swimmers (2 male; age: 20.0 ± 2.8; 6 female; age: 17.3 ± 1.9); elite level	Power time, recovery time, combined power time, power/recovery ratio and phases duration	Repeated measures ANOVA (R – L)	No side-to-side ≠ in power time, recovery time, combined power time, and power/recovery ratio ($p > 0.05$). Asymmetries in phases duration ($p < 0.05$). Greater asymmetry in the power than in the recovery phase ($p < 0.05$)
Becker & Havriluk (7), USA	19 competitive swimmers (12 males; 7 females); age: 15.4 ± 1.4	Peak hand force in freestyle (Adduction movement) and backstroke (Abduction movement) swimming	Effect size (R – L)	Bilateral ≠ were trivial and non-significant
de Jesus et al. (23), Portugal	9 male swimmers; age: 21.2 ± 5.7; national level	Force (F) and impulse (IMP) of hands and feet (vertical (VERT), horizontal (HOR) and lateral (LAT) axes), in two backstroke start variants (VERT and HOR handgrips), in four moments (starting signal, before hands-off, in hands-off, and before take-off)	SI = [P – NP / 0.5 (P + NP)] * 100; MBI + Effect size	Both backstroke start variants evidenced advantage of P side in VER and HOR F and IMP, and of NP side in LAT F and IMP
Dieguez & Barden (24), Canada	Without pain: 12 (6 male, 6 female); age: 20.1 ± 3.5. With pain: 12 (6 male, 6 female); age: 22.9 ± 5.7. Elite level	Hip and shoulder mean roll angles, at fast, medium and slow speeds of front crawl swimming	ASI = [B – NB / 0.5 (B + NB)] * 100; + Mixed ANOVA	Mean asymmetries: Shoulder: Without pain: 16.0% vs. With pain: 16.1% ($p = 0.98$). Hip: Without pain: 13.8% vs. With pain: 26.0% ($p = 0.01$)
dos Santos et al. (27), Brazil	18 male swimmers; age: 21.7 ± 5.0; national level	PF, mean force (MF), rate of force development (RFD), and IMP, at the begging, intermediate and end of tethered swimming (TS), in fast and slow groups, with unilateral and bilateral breathing patterns	Relative (%) difference between sides (R – L) + ANOVA	Side asymmetries in all propulsive force parameters ($p < 0.05$). Range: 7.0 – 37.2 %. No ≠ in asymmetries according to breathing preference or instants of the TS ($p > 0.05$). The fast group showed > PF and MF symmetry ($p < 0.05$)
dos Santos et al. (25), Brazil	20 competitive swimmers; age: 18.5 ± 3.8 (able-bodied)	Stroke dimensions (amplitude, width, depth, underwater time, recovery time), Index of coordination (IDC), and stroke phases	Mixed model ANOVA (D – ND)	Stroke dimensions and individual underwater phases did not differ between sides ($p > 0.05$), with exception of width and IDC in initial condition for fast group ($p <$

		(downsweep (DS), insweep (IS), upsweep (US), velocity DS, velocity IS, velocity US, velocity underwater) in fast and slow groups, in initial and final conditions		0.05), and width in final condition for fast group ($p < 0.05$)
Formosa et al. (33), Australia	8 male swimmers; age: 22.1±1.7; elite level	Minimum (MIN) and maximum (MAX) net force, time of MIN and MAX net force	Paired t-test (R – L)	Most swimmers showed asymmetries in MIN and MAX net forces ($p < 0.05$). No side ≠ in time of MIN and MAX net force for most swimmers ($p > 0.05$)
Formosa et al. (34), Australia	20 swimmers (10 male; age: 21.3 ± 3.1; 10 female; age: 21.3 ± 3.1; national level	Location of MIN and MAX net drag forces, timing variables (percentage of overlap, duration of underwater stroke), in B and NB conditions	SI = [B – NB / 0.5 (B + NB)] * 100; Chi-square test; ANOVA	Most participants presented symmetry when using the timing index (B condition 85% – NB condition 95%). The minority of participants presented symmetry when using the net drag force profile in B (MIN 15% - MAX 85%) and NB (MIN 15% - MAX 65%) conditions
Formosa et al. (35), Australia	20 swimmers (10 male; age: 21.3 ± 3.1 yr; 10 female; age: 21.3 ± 3.1 yr; national level	Location of MIN and MAX net drag forces, timing variables (percentage of overlap, duration of underwater stroke), in B and NB conditions	SI = [B – NB / 0.5 (B + NB)] * 100; Chi-square test; One-way ANOVA	Side-to side ≠ using the symmetry timing method in B ($p < 0.01$) and NB ($p < 0.01$) conditions. Using the net drag force symmetry method, between sides ≠ in B (MIN $p < 0.01$, MAX $p < 0.01$) and NB (MIN $p = 0.03$, MAX $p = 0.01$) conditions
Formosa et al. (36), Australia	19 swimmers (10 male; age: 21.2 ± 2.9; 9 female; age: 18.8 ± 3.1); elite level	Location of MIN and MAX net drag forces, timing variables (percentage of overlap, duration of underwater stroke), difference between peak values, in backstroke	SI = [R – L / 0.5 (R + L)] * 100; Two-way ANOVA	There were no significant ≠ between the distribution of asymmetry and/or symmetry for symmetry index MIN ($p = 0.819$) or MAX ($p = 0.973$) net drag force. Significant ≠ ($p = 0.001$) in the timing symmetry index with the majority of the participant's recording symmetrical results
Guignard et al. (38), France	8 male swimmers; age: 20.8 ± 3.0; elite level	Phase coupling, in pool swimming and flume swimming, in 8 speeds	ASI = [R – L / 0.5 (R + L)] * 100; > 10% = asymmetry	50% (pool) and 67.9% (flume) of the phase coupling values were asymmetrical
Morouço et al. (54), Portugal	18 competitive male swimmers; age: 15.6 ± 2.1	Mean and maximum PF, slope of forces	SI = [D – ND / 0.5 (D + ND)] * 100; paired t-test; Effect size	Both mean and maximum PF were > for the D side ($p < 0.05$). Mean symmetry index = 19.0 ± 14.0 (range 3.3 – 48.5%)
Nikodelis et al. (57), Greece	5 elite swimmers (2 male, 3 female); age: 18.9 ± 1.0; (competitive group)	Arm coordination (coupling between arms), in sprint and self-paced conditions	Absolute values presented graphically (R – L)	Between-hands asymmetry by the end-point trajectories, > in the non-competitive than in the elite swimmers. < asymmetries in self-paced than in sprint condition

Pereira et al. (59), Brazil	14 competitive swimmers (9 male, 5 female); age: 18.4 ± 4.9	MF and PF during butterfly stroke	SI = [D – ND / 0.5 (D + ND)] * 100; Paired t-test	MF: 8.9 ± 9.7 % ($p < 0.01$) PF: 12.6 ± 10.1 % ($p < 0.01$)
Psycharakis et al. (66), UK	15 swimmers (9 male; age: 21.3 ± 1.0; 6 female; age: 21.0 ± 2.8); university-level	Maximum force (F_{MAX}), minimum force (F_{MIN}) and mean force (F_{MEAN}); Normalised F_{MAX}, F_{MIN} and F_{MEAN}; stroke cycle IMP and time	SI = ((D-ND)/(D+ND))*2*100; Paired t-tests and Wilcoxon	No ≠ between D and ND arms ($p > 0.05$); ≠ between S and W sides ($p < 0.05$)
Psycharakis & McCabe (64), UK	20 male swimmers; age: 18.97 ± 2.4; international and national level	Shoulder and hip roll, in B and NB conditions	Paired t-test	In B condition, shoulder roll was > for the B side (59.9 vs. 50.4, $p < 0.01$); hip roll was not ≠ between sides (24.5 vs. 19.1, $p = 0.07$). No between sides ≠ seen in the NB conditions (shoulder: 51.9 vs. 53.3, $p = 0.69$; hip: 20.4 vs. 19.5, $p = 0.70$)
Psycharakis & Sanders (65), UK	10 male swimmers; age: 17.1 ± 0.9; international and national level	Shoulder and hip roll	SI = (2 (R – L) / (R + L)) * 100; Paired t-test	Bilateral asymmetries in both shoulder roll (-14.3 ± 10.9 %) and hip roll (6.1 ± 28.8 %), with > rolling to the L side ($p < 0.05$). No significant changes in the magnitude of asymmetries throughout the test ($p > 0.05$)
Santos et al. (71), Brazil	21 swimmers (13 male; 8 female); age: 18.5 ± 3.8 (able-bodied)	Amplitude (anteroposterior, mediolateral, VERT) and trajectory of the stroke; Time in underwater and recovery phases; IDC; DS, IS, and US phases; DS, IS, US and underwater phase speed	SI = [R – L / 0.5 (R + L)] * 100; > 10% = asymmetry	Asymmetry between sides in most of the tested variables (> 10.0%)
Seifert et al. (74), France	28 male swimmers; elite (age: 20.1 ± 3.3); regional (age: 20.7 ± 1.4); non-expert (age: 20.2 ± 1.6) level	Arm IDC, (swimmers divided in breathing patterns groups: R B, L B, bilateral B) - (swimmers divided in motor laterality groups: R, L, and mixed dominance)	Comparison of IDC R and IDC L; ANOVA; paired t-test	Side-to side ≠ in R B and L B groups ($p < 0.05$), but not for bilateral B group ($p > 0.05$), whatever skill group. Side-to-side ≠ in R and L groups ($p < 0.05$), but not for mixed dominance group ($p > 0.05$)
Seifert et al. (73), France	11 male swimmers; age: 18.6 ± 2.5; national level	Arm IDC, in 7 breathing patterns (2 strokes on the P B side (2P), 2 strokes on the NP B side (2NP), 3 strokes, apnea, simulation of 2NP, snorkel, and snorkel 2P)	SI = [P – NP / 0.5 (P + NP)] * 100; >10% = asymmetry; One-way ANOVA	Side-to-side ≠ in the patterns: 2P, 2NP, simulation of 2NP, and snorkel 2P ($p < 0.05$). SI values: 2P (21.2%), 2NP (-16.2%), 3 strokes (-1.4%), apnea (-4.1%), simulation of 2NP (-17.9%), snorkel (-4.8%), and snorkel 2P (-12.1%). The SI was ≠ between the breathing patterns ($p < 0.05$)
Silvatti et al. (77), Brazil	4 highly trained male swimmers	Hands trajectories (shape symmetry and amplitude) in butterfly, freestyle and breaststroke strokes	Descriptive statistics of absolute values	Two swimmers in butterfly and breaststrokes tasks showed asymmetric trajectories shapes and amplitude, favoring the R side. In freestyle, all swimmers

				presented symmetric hand trajectories, and two presented asymmetric amplitude
Tourny-Chollet et al. (80), France	13 male swimmers; age: 18.6 ± 2.5; national level	Arm IDC; Shoulders medial rotator muscles mean torque (MT), catch + pull relative duration	SI = [R – L / 0.5 (R + L)] * 100; or SI = [D – ND / 0.5 (D + ND)] * 100; >10% = asymmetry; Two-way ANOVA	All swimmers demonstrated coordination asymmetry and 8 displayed force asymmetry. The relative duration of catch + pull was > for the D (51.7 %) than for the ND arm (48.4 %) for the swimmers with force asymmetry ($p < 0.05$), but not different for swimmers with force symmetry (51.3 vs. 51.4, $p > 0.05$)

SI: symmetry index, R: right, L: left, S: stronger, W: weaker, ≠: difference, P: preferred, NP: non-preferred, MBI: magnitude based inference, ASI: asymmetry index, B: breathing, NB: non-breathing, D: dominant, ND: non-dominant.

Table 3. Summary of studies that measured asymmetries in swimming athletes during dry-land and in-water tests.

Study	Participants characteristics	Asymmetry variable(s) measured	Asymmetry method of analysis	Asymmetry main results
Carvalho et al. (19), Portugal	12 swimmers (7 male; age: 20.9 ± 3.4; 5 female; age: 19.0 ± 2.2); elite level	Peak force (PF) in tethered swimming (TS) (10 upper limb actions and 30s); Peak torque (PT), mean torque (MT), and mean power (MP) of upper limb simulated action, knee extension (EXT), and both combined (90-300°/s)	SI = (P – NP) * [0.5 * (P-NP)] ^ (-1) * 100; + Wilcoxon + Effect size	Similar force production between P and NP body sides ($p > 0.05$). No ≠ in SI between tests ($p > 0.05$)
dos Santos et al. (26), Brazil	18 competitive male swimmers; age 21.3 ± 4.6	PF and rate of force development (RFD)	SI = [S – W / 0.5 (S + W)] * 100; + paired t-test	Tethered test: PF 11% (p < 0.01), RFD 13% ($p < 0.05$); Land-based strength test: PF 14% ($p < 0.01$), RFD 17% ($p < 0.05$)
Evershed et al. (30), Australia	32 swimmers (15 males; age: 15.4 ± 2.5; 17 female; age: 15.1 ± 2.9); elite/national level	Clinical strength (PT of shoulder internal rotation (IR), external rotation (ER), abduction, adduction (ADD) and horizontal ADD); 3D kinematic (Thoracic rotation, elbow flexion (FLE), shoulder FLE and ADD); Bilateral hand force	SI = [R – L / 0.5 (R + L)] * 100; asymmetry = > 10% in clinical strength	Asymmetry of clinical strength were found in 84% of the swimmers. Compensatory strategies reduced the imbalances in hand force production to 60%. Symmetrical (n = 5), asymmetrical that compensate (n = 14), asymmetrical that do not compensate (n=13)
Hardt et al. (40), Australia	22 competitive swimmers (11 male; age: 13.6 ± 1.3; 11 female; age: 14.2 ± 1.0)	Track start performance (5m time); Jump height ($_{SL}$CMJ)	SI (> 10% = asymmetry) + Two-way ANOVA (P – NP)	Better performance using the preferred track start stance ($p < 0.05$). No clear ≠ between sides in $_{SL}$CMJ performance (> P n = 8, mixed n = 8, >NP n = 6)
Morais et al. (52), Portugal	18 swimmers (12 male, 6 female); age: 15.8 ± 1.6; national and international level	Upper limb lengths; Hand surface area (HAS); mean force (MF); peak force (PF); stroke intra-cycle thrust variation (ΔT).	SI = [D – ND / 0.5 (D + ND)] * 100; + One-way ANOVA + Effect size	Arm: 0.88% ($p = 0.79$, ES: 0.09); Forearm: 0.75% ($p = 0.74$, ES: 0.11); Upper limb: 0.59% ($p = 0.80$, ES: 0.08); HSA: -1.23% ($p = 0.70$, ES: 0.13); MF: 3.94% ($p = 0.50$, ES: 0.23); PF: 0.05% ($p = 0.93$, ES: 0.03); ΔT: -5.57% ($p = 0.13$, ES: 0.51)
Morais et al (53), Portugal	22 male swimmers; age: 15.9 ± 0.7; national level	Upper limb length; HSA; Handgrip strength; mean swimming speed (MV); peak swimming speed (PV); MF; PF; underwater stroke time (UST); ΔT; stroke intra-cycle speed variation (ΔS)	Paired t-test + Effect size (D – ND)	Differences in arm ($p = 0.02$, ES: 0.11) and forearm ($p = 0.04$, ES: 0.19) lengths, MV ($p < 0.01$, ES: 0.44), PV ($p < 0.01$), MF ($p = 0.04$, ES: 0.31), and ΔT ($p < 0.01$, ES: 0.64). No ≠ in HAS ($p = 0.11$, ES: 0.14), handgrip strength ($p = 0.45$, ES: 0.07), ΔS ($p = 0.08$, ES: 0.20), UST ($p = 0.98$, ES: 0.00), and PF ($p = 0.40$, ES: 0.11)
Morais et al. (51), Portugal	20 swimmers (10 male; age: 15.4±0.3; 10 female; age: 14.4 ± 0.2); national level	Upper limb lengths; HSA; MF; PF; ΔT,) in butterfly stroke.	Paired t-test + Effect size (D – ND)	No ≠ for males or females in any variables ($p > 0.05$), but in the ΔT in males ($p = 0.02$, ES = 0.66)

Sanders et al. (68), Australia	1 female breaststroke swimmer; international level	PT (60-180°s) - Knee: extension (EXT), FLE, EXT/FLE ratio; Shoulder: EXT, FLE, IR, ER, EXT/FLE ratio, IR/ER ratio; Wrists and ankles paths in breaststroke	Percentage differences (R – L)	Strength asymmetries range: 60°s = -3.4 to 17.4%; 180°s = -24.1 to 15.4%. Some bilateral ≠ in the movement pattern of the wrists and ankles

SI: symmetry index, P: preferred, NP: non-preferred, S: strong side, W: weak side, R: right, L: left, D: dominant, ND: non-dominant.

Table 4. Studies investigating the influence of asymmetries on swimming performance.

Study	Participants characteristics	Asymmetry test / metric	Performance outcome	Statistic method	Main results
de Jesus et al. (23)	9 male swimmers; age: 21.2 ± 5.7; national level	Force (F) and impulse (IMP) of hands and feet (vertical (VERT), horizontal (HOR) and lateral (LAT) axes), in two backstroke start variants (VERT and HOR handgrips), in four moments (starting signal, before hands-off, in hands-off, and before take-off)	Take-off velocity	Spearman's correlation	Negative correlations between asymmetries and take-off velocity. Hands: VERT IMP on HOR handgrip ($r = -0.70$, $p = 0.04$); HOR and VERT F in the start signal and before the hands-off on the VERT handgrip ($r = -0.72$, $p = 0.03$; $r = -0.70$, $p = 0.04$). Feet: HOR IMP in HOR and VERT handgrips ($r = -0.73$, $p = 0.02$; $r = -0.83$, $p < 0.01$); HOR F in VERT handgrip before hands-off and take-off and on hands-off ($r = -0.78$, $p = 0.01$; $r = -0.83$, $p < 0.01$; $r = -0.75$, $p = 0.02$)
dos Santos et al. (27)	18 male swimmers, fast (n =9), and slow (n= 9) groups; age: 21.7 ± 5.0; national level	Peak force (PF), mean force (MF), rate of force development (RFD), and IMP, during 2-minutes of maximal tethered swimming	Best 200m front crawl time	Factorial ANOVA	Fast group presented < asymmetries in PF (13.3 ± 1.8 vs.18.3 ± 1.9 – $p = 0.01$) and MF (7.0 ± 0.9 vs. 10.1 ± 1.0 – $p = 0.04$). No ≠ between groups for RFD (29.6 ± 4.8 vs. 37.2 ± 5.3 – $p = 0.69$) and IMP (14.5 ± 1.9 vs. 18.2 ± 2.3 – $p = 0.22$) asymmetries
Morouço et al. (54)	18 competitive male swimmers; age: 15.6 ± 2.1	PF and MF, during a maximal 30s tethered swimming test	Best 50m front crawl time	Independent t-test	No performance ≠ between swimmers with and without asymmetries
Phukan et al. (62)	38 swimmers (19 male; 19 female); age: 12.3 ± 1.2; regional and national level	$_{\text{SL}}$CMJ and $_{\text{SL}}$HJ performance	50m and 25m front crawl time; 50m and 25m kick time	Spearman's rho	No sig. correlations between asymmetries and sport-specific performance (r range = -0.007 – 0.303, $p > 0.05$)
Psycharakis et al. (66)	15 swimmers (9 male; age: 21.3 ± 1.0; 6 female; age: 21.0 ± 2.8); university-level	Maximum force (F$_{\text{MAX}}$), minimum force (F$_{\text{MIN}}$), mean force (F$_{\text{MEAN}}$) (absolute and normalized), stroke cycle IMP and time, during tethered swimming in four conditions	Best 50m front crawl time	Pearson's and Spearman's correlation	No sig. correlations ($p > 0.05$) between 50m best season time and symmetry index, absolute symmetry index, magnitude of ≠ or absolute magnitude of ≠ of the variables
Psycharakis & Sanders (65)	10 male swimmers; age: 17.1 ± 0.9 ; international level	Shoulder and hip roll (°)	Swimming velocity (200m)	Pearson's correlation	No sig. correlations ($p > 0.05$) between magnitude of asymmetries and swimming velocity

Santos et al. (71), Brazil	21 swimmers (13 male; 8 female); age: 18.5 ± 3.8 (able-bodied)	Amplitude (anteroposterior, mediolateral, VERT) and trajectory of the stroke; Time in underwater and recovery phases; Index of coordination, downsweep (DS), insweep (IS), and upsweep (US) phases; DS, IS, US and underwater phase speed	Technical Index	Kruskal-Wallis	No ≠ in asymmetry values between groups with high and low performance (technical index) ($p > 0.05$)

≠: difference(s), $_{\text{SL}}$CMJ: single-leg countermovement jump, $_{\text{SL}}$SLJ: single-leg standing long jump.