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# Effects of Successive Annual Training on Young Swimmers' Strength Asymmetries and Performance

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**Abstract:** This study aimed to compare changes in swimmers' performance, biomechanical variables, and strength asymmetries within two successive training years. Eight competitive age-group swimmers (four males and four females; age: 14.8 ± 1.3 years) were tested before and after the same 12-week mesocycle period within two successive years (Year-1, Year-2). The swimmers were timed in 50, 200, and 400 m, and the stroke rate (SR), stroke length (SL), and stroke index (SI) were calculated. SI was calculated by the product of SL with swimming speed. Dryland shoulder isometric strength (ISO), hand grip isometric strength test (HG), and in-water maximum 30 s tethered swimming force (TF) were evaluated. The asymmetry index was calculated using ISO, HG, and TF tests as $[(Fd - Fnd)/0.5 \times (Fd + Fnd)] \times 100$, where Fd is strength in the dominant hand and Fnd is strength in the non-dominant hand. Performance time improved in 200 and 400 m, while the asymmetry indices calculated by the ISO, HG, and TF tests were similar after 12 weeks of training in both Year-1 and Year-2 ($p$ = 0.01). Changes (Δ) in HG strength asymmetries correlated with Δ in 200 and 400 m in Year-2 ($r$ = 0.78–0.87, $p$ = 0.01). The asymmetry index does not change after two successive years of training but may be connected to performance changes in 200 and 400 m front crawl.

**Keywords:** strength asymmetries; shoulder isometric test; hand grip isometric test; tethered swimming test

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## 1. Introduction

Swimmers use both their arms and legs optimally to minimize resistive drag and increase propulsion during swimming [1]. Most of the time, swimmers may use one of their limbs (arm or leg) more efficiently compared to the other due to asymmetries in strength [2]. Thus, asymmetries may affect swimmers' technique as well as performance after a period of training [3]. It is known that comparable force application from both the right and left sides of the body may positively affect swimming performance by lowering intracycle velocity variations [1]. Moreover, more than 96% of the human population presents a noticeable asymmetry level [4], especially in cycling and continuous sports activities [2,5].

The evaluation of strength asymmetries for upper limbs may be assessed with specific dryland tests (i.e., shoulder isometric strength and hand grip isometric strength) [6,7] or with a specific in-water evaluation such as the 30 s tethered swimming test [8]. Recently, a moderate to large direct relationship was observed between dryland strength and swimming force production [9] and performance during a training set (i.e., 4 × 50 m) [10]. However, no relationship was found between strength asymmetries calculated by a 30 s tethered swimming test and a shoulder isokinetic test [9]. Additionally, it was found that bilateral asymmetries and peak force production during a maximum isometric voluntary test were similar between tethered swimming and isometric strength tests [11]. Recently, it was highlighted that evaluating strength asymmetries in different angular velocities (60°/s or 180°/s) during an isokinetic test may result in different levels of asymmetries [12], and this may affect swimmers' coordination during propulsion in swimming [12]. In addition, strength asymmetries may be associated with swimmers' technical characteristics, such as stroke rate (SR) or stroke length (SL), or with muscular imbalances during a tethered swimming test [9].

By emphasizing muscular imbalances, it was observed that shoulder rotator muscles became stronger than antagonists [13]. This may increase muscle imbalance and the risk of injury during propulsion after a 16-week macrocycle training period [13]. Furthermore, biological maturity has been proposed as an important factor that may affect swimmers' biomechanical characteristics and be associated with their efficiency in the water [14]. It is well documented that higher-level swimmers have better efficiency during propulsion due to their better swimming technique [14]. Additionally, swimmers' biological maturation will likely affect their dryland and in-water strength gains or the likely induced asymmetries after a training period. Recently, it was reported that bone asymmetries in tennis players may increase substantially, which is connected with maturity status in both males and females [15].

To our knowledge, however, there is no study in swimming testing strength asymmetries in dryland and in-water strength changes during successive annual training plans. Therefore, the purpose of the current study was to examine the influence of swimming training on performance, strength asymmetries, dryland, and in-water strength changes as well as biomechanical characteristics after twelve weeks including similar training content applied in two successive annual cycles of training. We hypothesized that swimmers' strength asymmetries will differ between the successive annual training plans. Furthermore, the changes in swimmers' strength asymmetries will be associated with changes in their biological maturation.

## 2. Materials and Methods

### 2.1. Participants

Eight regional-level competitive swimmers (four male and four female) specialized in competitive distances ranging from 50 to 400 m volunteered to participate in this study (age: 14.8 ± 1.3 years, body mass: 55.8 ± 4.9 kg, and height: 163.8 ± 9.9 cm). The age range of each swimmer is presented in Table 1. Their recent 50, 200, and 400 m front crawl competitive times (29.7 ± 1.8, 136.5 ± 9.6, and 301.8 ± 22.3 s) corresponded to 413 ± 63, 485 ± 40, and 460 ± 99 Word Aquatic points, respectively. All swimmers had participated in the national age-group championship of the previous year, and they had a competitive training background of 4.6 ± 1.7 years. As inclusion criteria, each swimmer needed to meet the following: (i) be free from injury and (ii) indicate no use of medication before or during the training period. After a thorough explanation of this study's procedures, all swimmers and their legal guardians signed a consent form accepting their participation in this study. The local institutional review board approved the experimental protocol (approval number: 1111) according to the Helsinki Declaration.

**Table 1.** The range of age of each swimmer that participated in the current study.

| Swimmers | Range of Age (Years) |
|---|---|
| 1 | 15.4 to 16.7 |
| 2 | 13.1 to 14.4 |
| 3 | 14.2 to 15.5 |
| 4 | 14.1 to 15.4 |
| 5 | 13.4 to 14.7 |
| 6 | 11.9 to 13.2 |
| 7 | 16.8 to 18.1 |
| 8 | 13.8 to 15.1 |

### 2.2. Study Design

A one-group repeated-measure design was applied with pre-training and post-training period measurements during two consecutive annual training cycles. Pre and post measurements in both years were applied during the same 12-week mesocycle of a specific preparation training period. Swimmers were tested in four time points, two for each training cycle, before (Pre) and after (Post) a 12-week training period (Year-1: Pre-1 and Post-1 vs. Year-2: Pre-2 and Post-2; Figure 1). All tests as well as training sessions were completed at the same time of the day (6:00 to 8:00 p.m.) in a 50 m outdoor swimming pool with a water temperature of 27 °C. Ambient temperature during testing ranged between 28 and 30 °C.

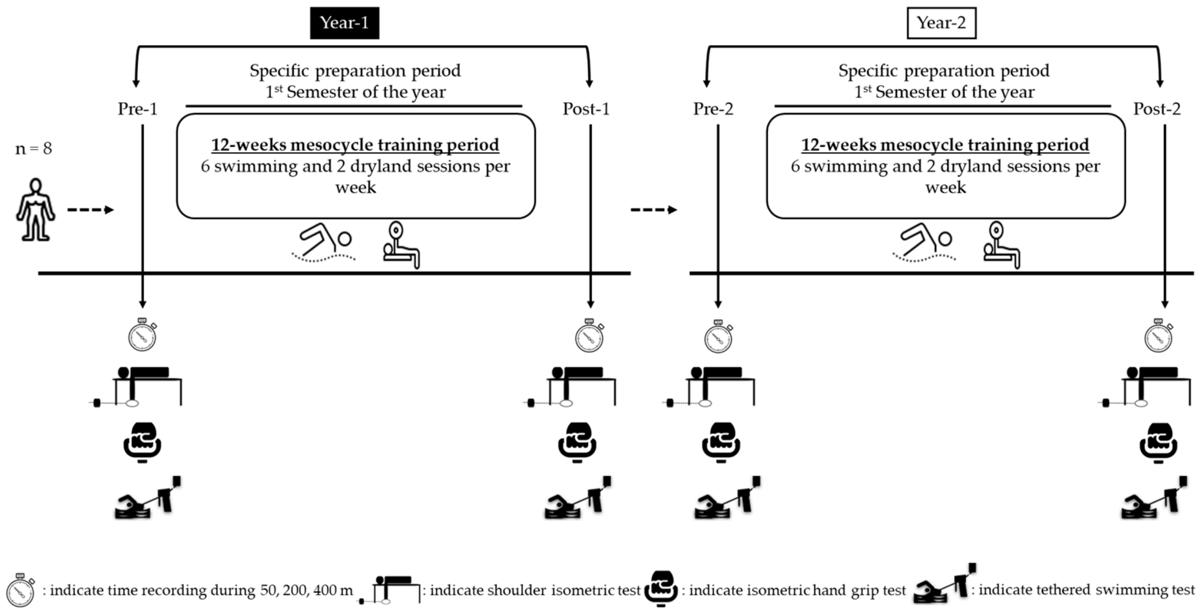


**Figure 1.** The experimental design of the study.

### 2.3. Testing Procedures

Before the testing procedures in the time points Pre-1, Post-1, Pre-2, and Post-2, body mass and body height (Seca, Hamburg, Germany) were measured, and swimmers' biological maturation was evaluated according to Tanner and Whitehouse [16]. During the same session, after an 800 m standardized warm-up (400 m front crawl, 4 × 50 m kicks, and 4 × 50 m front crawl swim with progressively increasing speed), swimmers participated in an increasing intensity test consisting of a 5 × 200 m front crawl on a 5 min cycle to calculate the speed corresponding to the second lactate threshold (sLT). The sLT was determined by the x-axis projection of the intersection of the lines connecting the two higher and three lower points of the speed lactate curve [17]. The sLT was used to control the training content and to classify training zones during the 12-week mesocycle training.

On the following three days and 24 h apart, swimmers performed swimming tests with maximum intensity. On day 1, the swimmers performed 50, 200, and 400 m front crawl tests with a 30 min recovery period between each test, including a 5 to 10 min active recovery period. In all swimming tests, performance time was recorded (HS-80 TW-$_1$EF, CASIO, Tokyo, Japan), and stroke rate (SR) was calculated by the time taken to complete 3 stroke cycles. Stroke length (SL) was calculated by the ratio of swimming speed to SR. The stroke index (SI) was calculated by the product of SL and swimming speed. Higher SI values indicate increased arm efficiency during swimming. All biomechanical variables were measured every 50 m during the 200 and 400 m tests. SR, SL, and SI were averaged to obtain one value for each test in each time point (Pre-1, Post-1, Pre-2, and Post-2), which was used for the statistical analysis.

On day 2, the swimmers performed a standardized warm-up (medicine ball throws and arm swings) before the shoulder isometric (ISO) and hand grip (HG) isometric strength evaluations. ISO was tested during two six-second maximum efforts for each upper limb, including one-minute rest period between efforts, as described by Aujouannet et al. [6], using a piezoelectric dynamometer (MuscleLab; Ergotest, Stathelle, Norway). Swimmers were in a prone position with a shoulder-to-hand angle of 90°. The mean values derived from each limb were used in statistical analysis. Fifteen minutes after the ISO evaluation, an HG isometric strength test was conducted. Swimmers applied two maximum efforts in each upper limb using an adjustable mechanical hand dynamometer (Takei TKK-5001, Grip-A, Tokyo, Japan). A one-minute rest period was allowed between the two efforts in each upper limb. The mean value of both upper limbs was used for the statistical analysis.

On day 3, after a five-minute standardized in-water warm-up, swimmers performed a 30 s front crawl tethered swimming sprint (TF) [18] using a piezoelectric transducer to measure the swimming-specific force (MuscleLab; Ergotest, Stathelle, Norway).

### 2.4. Determination of Asymmetries

All swimmers mentioned their dominant and non-dominant sides and upper limbs. The asymmetry index was calculated and examined for dryland strength testing evaluation of ISO and HG and in-water TF. The asymmetry index was calculated using the following equation, which was described by Tourny-Chollet et al. [19]:

$$\text{Asymmetry index} = \lfloor (\text{Fd} - \text{Fnd})/0.5 \times (\text{Fd} + \text{Fnd}) \rfloor \times 100 \quad (1)$$

where Fd is the force produced by the dominant upper limb and Fnd is the force produced by the non-dominant limb. The values between −10 and 10% indicate symmetry, and values greater than −10 and 10% indicate asymmetry between upper limbs [19].

### 2.5. Training Period and Determination of Training Intensity

The training content was recorded daily with the aim of achieving the same training volume and intensity in both 12-week specific preparation mesocycle periods. Swimmers followed their normal swimming training, which consisted of six swimming training sessions and two dryland training sessions per week. The swimming training distance was recorded, and training intensity was estimated by the five levels which were identified by the speed–lactate curve proposed by Mujika et al. [20]. The duration of the swimming training session ranged from 90 to 120 min.

The dryland training sessions included muscular endurance resistance training throughout the mesocycle period (i.e., 3 to 4 sets × 12 to 20 repetitions @40–50% of 1-repetition maximum with 30 s rest). Moreover, each dryland training session of 50 to 60 min duration comprised eight exercises, namely four for upper limbs (bench press, latissimus pulldown, and seated rowing) and four for lower limbs (half squat, leg press, leg extension, and seated hip adduction). The muscular endurance resistance training sessions were applied 20 min after the swimming training session.

### 2.6. Statistical Analysis

A Kolmogorov–Smirnov test was used to examine the normal distribution of the data. Mauchly's test was used to test for sphericity, and Greenhouse–Geisser was used when the assumption of sphericity was not met. Analysis of variance on repeated measures in two factors (2 years × time points) was used for all dependent variables (performance time, SR, SL, SI, ISO, HG, TF, and asymmetries). Tukey's honest significant difference was used as a post hoc test to compare the means when significant F ratios were found. To estimate the size of the main effects and interaction, the partial eta-squared ($\eta_p{}^2$) values from the analysis of variance were used. $\eta_p{}^2$ was considered small if the value was $\leq$0.01, medium if it was $\leq$0.06, and large if it was $\geq$0.14. The $\eta_p{}^2$ value for the sample size in the present study (n = 8) examined in two consecutive years and in four time points of measurement resulted in a power of analysis corresponding to 0.60 [21]. In addition, the differences (Δ) were estimated for asymmetries that were evaluated in ISO, HG, and TF tests from post- to pre-training measurements in both years (Year-1, Year-2). Moreover, the percentage of Δ values (% Δ) was calculated from post- to pre-training measurements in both years for all dependent variables. A T-test for paired samples was used to compare the %Δ values for all dependent variables. Pearson correlation was used to examine relationships between Δ values in measured variables, and it was qualitatively interpreted as small ($r$ = 0.1–0.3), moderate ($r$ = 0.3–0.5), large ($r$ = 0.5–0.7), very large ($r$ = 0.7–0.9), or nearly perfect ($r$ > 0.9) [22]. Data are presented as mean ± SD. Statistical significance was set at $p \leq 0.05$.

## 3. Results

### 3.1. Training Volume and Training Intensity

The total distance of training within the 12-week specific preparation mesocycle period of training was similar in Year-1 compared to Year-2 (Year-1: 269,500 vs. Year-2: 302,225 m; $p > 0.05$). Moreover, the distance that swimmers covered in each training intensity was also similar in Year-1 compared to Year-2 ($p > 0.05$). Swimmers covered different distances in level I (~2 mmol.L$^{-1}$; Year-1: 136,100 vs. Year-2: 169,725 m), level II (~4 mmol.L$^{-1}$; Year-1: 100,700 vs. Year-2: 89,800 m), level III (~6 mmol.L$^{-1}$; Year-1: 24,000 vs. Year-2: 28,850 m), level IV (~10 mmol.L$^{-1}$; Year-1: 1800 vs. Year-2: 3600 m), and in level V (maximum intensity; Year-1: 6250 vs. Year-2: 10,150 m).

### 3.2. Biological Maturity

The biological maturity level of each swimmer according to the Tanner stage is presented in Table 2. Swimmers increased their biological maturity in Year-2 compared to Year-1 ($p$ = 0.01; Figure 2), and their biological maturity increased after the 12-week training period in both years ($p$ = 0.01; Figure 2).

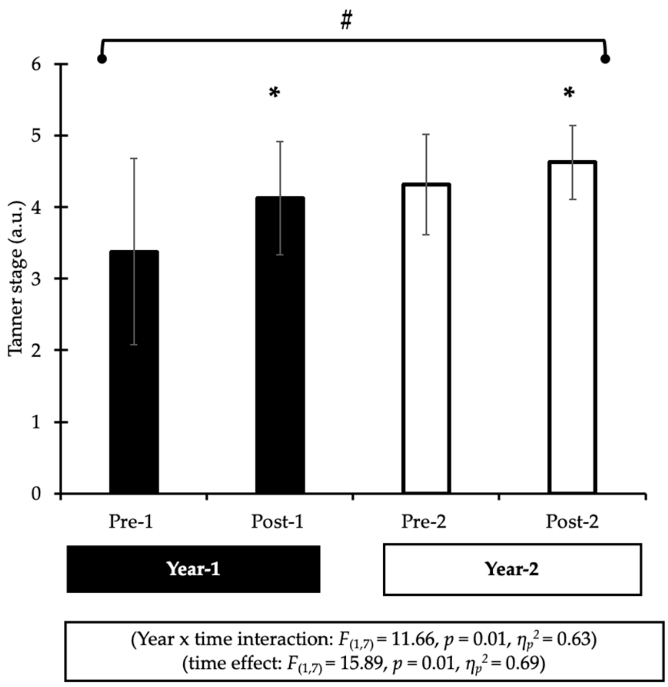


**Figure 2.** Swimmers' biological maturity changes according to Tanner stage in Year-1 and Year-2 and pre- (Pre-1, Pre-2) to post-training (Post-1, Post-2) measurements. *: $p > 0.05$, Pre-1 vs. Post-1 and Pre-2 vs. Post-2; #: $p > 0.05$, Pre-1 vs. Pre-2 and Post-1 vs. Post-2.

**Table 2.** Swimmers' biological maturity according to Tanner stage for Year-1 and Year-2 for pre to post 12-week specific mesocycle training period.

| | Year-1 | | Year-2 | |
|---|---|---|---|---|
| **Swimmers** | **Pre** | **Post** | **Pre** | **Post** |
| 1 | 5 | 5 | 5 | 5 |
| 2 | 3 | 4 | 4 | 4.5 |
| 3 | 3 | 4 | 4 | 4.5 |
| 4 | 3 | 4 | 4 | 4.5 |
| 5 | 4 | 4 | 4 | 4.5 |
| 6 | 2 | 2.5 | 3 | 3.5 |
| 7 | 3 | 4 | 5 | 5 |
| 8 | 5 | 5 | 5 | 5 |

### *3.3. Performance and Biomechanical Variables in 50, 200, and 400 m Tests*

#### 3.3.1. Performance

Performance time in Year-1 compared to Year-2 was no different in the 50 and 400 m tests, while it decreased in the 200 m test (indicating improvement; Table 3). Performance time decreased in the 200 and 400 m test at Post-1 and Post-2 compared to Pre-1 and Pre-2, respectively, but did not change in the 50 m test in both years (Table 3).

**Table 3.** Performance time changes in 50, 200, and 400 m front crawl tests pre and post 12 weeks of specific preparation training period in Year-1 (Pre-1 and Post-1) and Year-2 (Pre-2 and Post-2).

| Performance Time (s) | Year-1 | | | Year-2 | | | Year-1 vs. Year-2 Effect | Pre vs. Post Effect |
|---|---|---|---|---|---|---|---|---|
| | **Pre-1** | **Post-1** | **%Δ** | **Pre-2** | **Post-2** | **%Δ** | | |
| 50 m | 31.9 ± 2.5 | 31.5 ± 2.1 | −1.1 ± 3.0 | 31.8 ± 2.3 | 30.5 ± 1.9 | −4.3 ± 5.9 | $p = 0.27$ | $p = 0.11$ |
| 200 m | 158.5 ± 15.1 | 147.4 ± 11.4 * | −7.6 ± 6.2 | 149.7 ± 11.1 † | 145.1 ± 9.7 †* | −3.2 ± 5.8 | $p = 0.01$ | $p = 0.01$ |
| 400 m | 323.9 ± 23.8 | 315.9 ± 30.3 * | −2.8 ± 4.1 | 315.2 ± 20.4 | 306.5 ± 18.5 * | −2.8 ± 1.7 | $p = 0.08$ | $p = 0.01$ |

* $p > 0.05$, Pre-1 vs. Post-1 and Pre-2 vs. Post-2; † $p > 0.05$, Year-2 vs. Year-1; %Δ, percentage difference between post- and pre-training measurements in Year-1 and Year-2.

#### 3.3.2. Biomechanical Variables

Stroke rate: The SR in Year-2 compared to Year-1 decreased in the 50 m test ($F_{(1,7)} = 9.30$, $p = 0.01$, $\eta_p^2 = 0.57$ [large]; Table 4) but was no different in the 200 and 400 m tests ($p > 0.05$, Table 4). The SR was no different at Pre-1 and Pre-2 compared to Post-1 and Post-2, respectively, in all swimming tests ($p > 0.05$; Table 4).

Stroke length: The SL increased in all swimming tests in Year-2 compared to Year-1 ($F_{(1,7)} = 8.62$ to 19.46, $p = 0.01$ to 0.02, $\eta_p^2 = 0.55$ to 0.72 [large]; Table 4), and it remained unchanged during the 50 and 400 m tests at Pre-1 and Pre-2 compared to Post-1 and Post-2, respectively ($p > 0.05$, Table 4). However, the SL increased during the 200 m test at Post-1 and Post-2 compared to Pre-1 and Pre-2, respectively, in Year-1 and Year-2 ($F_{(1,7)} = 10.20$, $p = 0.01$, $\eta_p^2 = 0.59$ [large]; Table 4).

Stroke index: The SI increased in Year-2 compared to Year-1 in all swimming tests ($F_{(1,7)} = 6.86$ to 19.00, $p = 0.01$ to 0.03, $\eta_p^2 = 0.49$ to 0.73 [large]; Table 4). In addition, the SI increased in Post-1 and Post-2 compared to Pre-1 and Pre-2, respectively, in the 200 and 400 m tests ($p < 0.05$; Table 4).

**Table 4.** Stroke rate (SR), stroke length (SL), and stroke index (SI) changes in 50, 200, and 400 m front crawl test pre and post 12-weeks of specific preparation training period in Year-1 (Pre-1 and Post-1) and Year-2 (Pre-2 and Post-2).

| Swimming Tests | Year-1 | | | Year-2 | | |
|---|---|---|---|---|---|---|
| | **Pre-1** | **Post-1** | **%Δ** | **Pre-2** | **Post-2** | **%Δ** |
| | **SR (cycles·min$^{-1}$)** | | | | | |
| 50 m | 51.8 ± 3.9 | 52.0 ± 5.2 | 0.3 ± 10.7 | 47.9 ± 3.5 † | 50.2 ± 4.1 † | 4.2 ± 7.5 |
| 200 m | 43.9 ± 2.7 | 44.9 ± 4.2 | 1.8 ± 5.4 | 42.8 ± 3.1 | 43.3 ± 5.1 | 0.6 ± 0.3 |
| 400 m | 44.6 ± 2.7 | 43.2 ± 2.3 | 1.2 ± 6.8 | 41.3 ± 3.2 | 41.8 ± 3.2 | 0.8 ± 7.4 |
| | SL (m·cycle$^{-1}$) | | | | | |
| 50 m | 1.84 ± 0.16 | 1.86 ± 0.26 | 0.5 ± 8.1 | 1.98 ± 0.16 † | 1.97 ± 0.19 † | -0.7 ± 6.1 |
| 200 m | 1.75 ± 0.21 | 1.84 ± 0.26 * | 4.9 ± 4.8 | 1.89 ± 0.22 † | 1.94 ± 0.23 †* | 2.2 ± 2.9 |
| 400 m | 1.75 ± 0.19 | 1.78 ± 0.25 | 1.1 ± 6.8 | 1.86 ± 0.22 † | 1.89 ± 0.19 † | 1.5 ± 6.6 |
| | SI (m$^2$·s$^{-1}$·cycle$^{-1}$) | | | | | |
| 50 m | 2.91 ± 0.44 | 2.98 ± 0.56 | 1.7 ± 5.8 | 3.14 ± 0.43 † | 3.25 ± 0.46 † | 3.2 ± 8.2 |
| 200 m | 2.24 ± 0.47 | 2.53 ± 0.53 * | 11.2 ± 8.1 | 2.56 ± 0.48 † | 2.69 ± 0.45 †* | 5.1 ± 5.6 |
| 400 m | 2.19 ± 0.39 | 2.30 ± 0.52 * | 3.5 ± 8.5 | 2.39 ± 0.43 † | 2.48 ± 0.38 †* | 4.2 ± 6.3 |

* $p > 0.05$, Pre-1 vs. Post-1 and Pre-2 vs. Post-2; † $p > 0.05$, Year-2 vs. Year-1; %Δ, percentage difference between post- and pre-training measurements in Year-1 and Year-2.

### 3.4. Shoulder Isometric Strength, Hand Grip Isometric Strength, and Tethered Force

Shoulder isometric strength: ISO was similar in Year-2 compared to Year-1 (Figure 3) and did not change at Post-1 and Post-2 compared to Pre-1 and Pre-2, respectively, in both years (Figure 3). ISO was higher at Pre-2 compared to Pre-1 (Figure 3a). The %Δ of ISO was higher in Year-2 compared to Year-1 (−12.8 ± 14.8% vs. 10.1 ± 4.7%, respectively; $p = 0.01$).

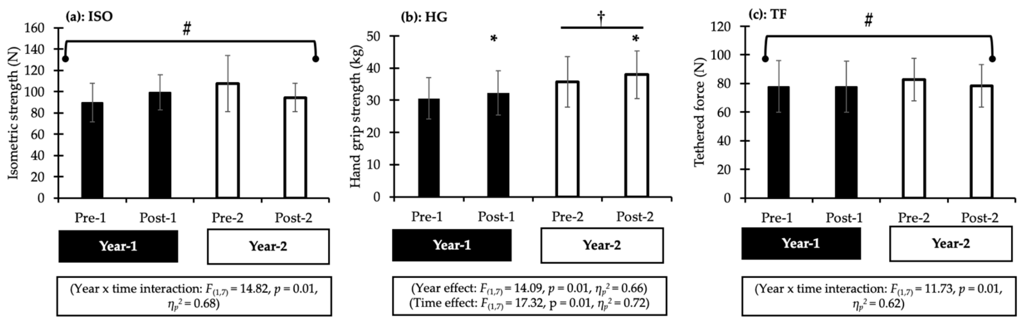


**Figure 3.** Shoulder isometric strength [ISO, panel (**a**)], hand grip isometric strength [HG, panel (**b**)], and tethered force [TF, panel (**c**)] changes in Year-1 and Year-2 for pre- and post-training measurements (Pre-1, Post-1, Pre-2, and Post-2). * $p < 0.05$, Post-1 vs. Pre-1 and Post-2 vs. Pre-2; # $p < 0.05$, Pre-2 compared to Pre-1 for ISO and TF and Post-2 compared to Post-1 for TF; † $p < 0.05$, Year-1 vs. Year-2.

Hand grip isometric strength: HG increased in Year-2 compared to Year-1 (Figure 3). HG increased at Post-1 and Post-2 in both years compared to the Pre-1 and Pre-2 values, respectively (Figure 3b). The %Δ of HG was similar between Year-1 and Year-2 (5.2 ± 7.0% vs. 6.2 ± 2.9%; $p = 0.01$).

Tethered swimming force: TF was higher in Pre-2 compared to Pre-1, while TF was lower in Post-2 compared to Post-1 (Figure 3c). In addition, %Δ of TF was higher in Year-2 compared to Year-1 (−5.9 ± 4.9% vs. −0.1 ± 0.4%; $p = 0.01$), respectively.

### 3.5. Strength Asymmetries Evaluation

Strength asymmetries evaluated from the dryland (HG and ISO) and in-water (TF) tests were similar in Year-1 compared to Year-2 (Table 5) without any change at the pre-training period compared to the post-training period in both years ($p > 0.05$; Table 5). The Δ values of asymmetries were similar for ISO, HG, and TF ($p > 0.05$; Table 5).

**Table 5.** Changes in the index of strength asymmetries that were evaluated from shoulder isometric strength (ISO), hand grip isometric strength (HG), and tethered swimming test (TF) pre and post 12 weeks of specific preparation training in Year-1 (Pre-1 and Post-1) and Year-2 (Pre-2 and Post-2).

| Strength Variable | Year-1 | | | Year-2 | | | Year-1 vs. Year-2 Effect | Pre vs. Post Effect |
|---|---|---|---|---|---|---|---|---|
| | Pre-1 | Post-1 | Δ | Pre-2 | Post-2 | Δ | | |
| HG | 3.34 ± 7.77 | 0.30 ± 6.69 | −3.0 ± 6.3 | 2.99 ± 2.69 | 3.15 ± 3.24 | 0.2 ± 1.3 | $p = 0.62$ | $p = 0.22$ |
| ISO | 1.47 ± 8.12 | 0.69 ± 7.45 | −0.8 ± 5.6 | 3.07 ± 8.00 | 3.80 ± 14.91 | 0.7 ± 12.9 | $p = 0.52$ | $p = 0.99$ |
| TF | 2.24 ± 2.46 | 1.34 ± 2.45 | −0.9 ± 2.9 | 0.81 ± 11.71 | 3.12 ± 11.48 | 2.3 ± 9.1 | $p = 0.96$ | $p = 0.67$ |

Δ: the difference between post- and pre-training measurements in Year-1 and Year-2.

### 3.6. Correlations

In Year-1, the calculated Δ values for ISO in Pre-1 vs. Post-1 were positively correlated with the Δ of swimmers' Tanner stage at the corresponding period ($p = 0.01$; Figure 4a). Moreover, in Year-2, the calculated Pre-2 vs. Post-2 Δ values of performance time in the 200 m and 400 m tests were positively correlated with corresponding Δ values of HG strength asymmetries ($p = 0.01$; Figures 4b and 4c, respectively). In Year-2, the calculated Pre-2 vs. Post-2 Δ values of SR in the 50 and 200 m tests were negatively correlated with the corresponding Δ values of TF asymmetries (50 m, r = −0.71, $p = 0.01$; 200 m, r = −0.94, $p = 0.01$).

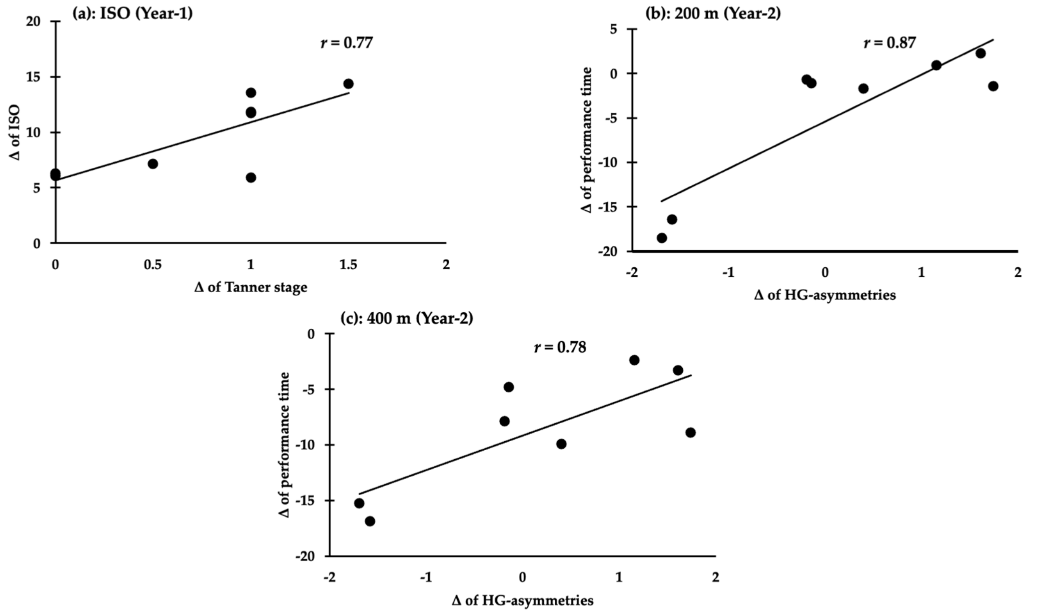


**Figure 4.** Correlations of Δ values of swimmer's Tanner stage with ISO in Year-1 [panel (**a**)] and 200 and 400 m changes with Δ of asymmetries evaluated by HG test in Year-2 [200 m, panel (**b**); 400 m, panel (**c**)].

## 4. Discussion

The current study examined the changes that occurred after 12 weeks of specific preparation swimming training mesocycles, applied in two successive annual training cycles, on performance, dryland, and in-water strength asymmetries as well as on biomechanical characteristics. The swimmers improved their performance time as well as SL and SI in the 200 and 400 m tests after both 12-week periods of training. Furthermore, the swimmers were faster and presented higher SL and SI values in Year-2 compared to Year-1 in the 200 m test. In addition, the strength asymmetries measured by the ISO, HG, and TF tests were similar in Year-1 and Year-2 after the 12-week specific preparation periods in both years. ISO and TF strength were higher in Year-2 compared to Year-1, but only HG improved after both 12-week specific preparation periods. In addition, the Δ values of ISO were positively correlated with the maturation stage, and the Δ values of HG asymmetries were correlated with performance time in the 200 and 400 m tests.

### 4.1. Performance and Biomechanical Variables

The swimmers managed to improve their performance in the 200 and 400 m tests during the 12-week mesocycle period of training both in Year-1 and Year-2. Comparable findings reported in previous studies indicate a performance improvement of 2% to 4% in distances of 25 to 400 m after 6 to 12 weeks of training [23–25] or after a year-round training plan [26]. The swimmers may have improved their aerobic endurance after the 12-week training period. This may be explained by improvements in aerobic indices such as critical speed, speed corresponding to 4 $mmol{\cdot}L^{-1}$, or the second lactate threshold after a 12-week specific preparation period [27]. Additionally, it is worth noting that the swimmers covered most of the swimming distances in training intensities corresponding to 2 to 6 $mmol{\cdot}L^{-1}$ during both 12-week specific preparation periods in the present study. This training intensity domain relates to the swimmers' aerobic capacity improvement [20]. Despite there being no significant change from Year-1 to Year-2 in the 400 m test, a large effect size was calculated ($\eta_p{}^2 = 0.37$). The interaction of swimmers' biological status and changes in aerobic or anaerobic ability and maximum strength between the two successive years may explain such changes [28]. Recent findings have shown a link between performance or grip strength and biological maturation in adolescent boys and girls [29].

Moreover, the swimmers managed to increase SL and SI in the 200 and 400 m tests. Similar changes were reported in a previous study in a 4 × 50 m test [23]. However, the swimmers followed a different training program during three swimming sessions (sprint training) compared to the present study (mainly aerobic). However, in agreement with the present study, all swimmers performed two dryland training sessions per week. Possibly, neuromuscular and mechanical adaptations occurred after both 12-week specific preparation periods in which the swimmers performed six swimming and two dryland training sessions per week. Then, the combined effect of effective dryland training and aerobic endurance improvement facilitated performance at Post-1 and Post-2 testing. Additionally, the swimmers managed to increase their dryland and in-water strength from Year-1 to Year-2. The increased SL and SI in Year-1 and Year-2 may indicate that the swimmers applied more propulsive force during the 200 and 400 m tests without affecting their swimming economy [30].

Interestingly, performance time was improved in middle swimming distances and not in short distances (50 m) because the training included a great total distance at an intensity corresponding to 2 to 6 $mmol{\cdot}L^{-1}$, which is known to be associated with aerobic-related indices [20,27]. The short total distance covered in sprint training may not be adequate to improve 50 m performance. However, it should be reported that all tests in the present study were conducted before and after a specific preparation period of the first semester of the year when training intensity progressively increases but it is not at the maximum [26].

### 4.2. Strength Asymmetries

The strength asymmetries calculated from the dryland (ISO and HG) and in-water strength (TF) tests were similar between Year-1 and Year-2 and at pre-training compared to post-training after both 12-week specific preparation periods. We found no relationship between the Δ values of the ISO and TF tests with the Δ values of asymmetries calculated by each test, respectively. This finding comes partially in agreement with a previous study where no strong relationships between asymmetries calculated by TF and isokinetic tests were reported [9]. In the current study, swimmers followed similar intensity and volume of swimming training, and this may explain the similarity reported for swimmers' asymmetries and strength calculated by the ISO, HG, and TF tests. However, it is possible that a different method of evaluation (i.e., isokinetic test) [9] is required to identify strength asymmetry changes during two consecutive years.

We observed that the Δ of asymmetries calculated by the HG test was positively correlated with the Δ of performance in the 200 and 400 m tests. In swimming studies, there is a discrepancy between performance time relationships and strength asymmetries. Some studies indicate a negative relationship between asymmetries and swimming performance ($r = -0.70$ to $-0.83$) [31], while others report no relationship [32,33]. A negative relationship means that increased strength asymmetry will increase (indicating deterioration) the swimmer's performance time. In the current study, a positive relationship was found between strength asymmetries and performance time. This may be attributed to the different methodology that was followed in each study (i.e., different equations to evaluate strength asymmetries and performance tests) or the swimmer's competitive level and biological maturity.

Despite possible methodological discrepancies between studies, this finding indicates that if swimmers increase their dryland strength index of asymmetry, their performance time may deteriorate during the 200 and 400 m tests (see Figure 4). To our knowledge, this is the first study that identified a relationship between dryland strength asymmetries and performance in middle-distance tests. Variations in swimmers' maximum strength due to increased biological maturity or positive dryland training adaptations (i.e., motor unit recruitment) during the 12-week training period may have affected the land strength asymmetries and swimming performance. Swimmers in the current study were not at a high competitive level, and this may have affected potential dryland (i.e., maximum strength and strength asymmetries) and in-water (asymmetries or inter-arm coordination) adaptations after a training period. Whatever the case, the index of asymmetry was within the normal limits, thus not allowing a direct connection with performance.

Moreover, we found strong relationships between the index of asymmetry calculated by the TF test and swimmers' biomechanical variables in Year-2. A recent review highlighted that asymmetries in swimming are more related to in-water tests (i.e., 30 s tethered swimming test) than dryland tests (i.e., shoulder isometric strength test) [34]. This outcome highlights that asymmetry observed in water is more related to swimming technique adaptations after the aquatic environment and to a lesser extent to muscular imbalances [35]. Similar findings were reported in a previous study [9] which examined the relationship derived from a 30 s TF test and swimmer's technique. The authors explained that the behavior of the index of asymmetry may adjust to swimmers' cycle patterns during a 30 s tethered swimming test and that this is a reliable test to identify in-water asymmetries [8,9,36].

However, it should be noted that swimmers became more biologically mature from Year-1 to Year-2, and this may have affected the strength and biomechanical outcomes according to the dryland and in-water asymmetries [14]. Recently, it was highlighted that inter-arm bone mass and size asymmetries in children tennis players are specific to maturity status [15]. This is partially indicated by the relationship found between the Δ of ISO and the Δ of the Tanner stage (see Figure 4) as well as from difference in relationships indicated between the Δ asymmetries calculated by the TF test and the Δ of SR during the 50 and 200 m tests in Year-2. There are some limitations in the present study that should be mentioned. A small sample size, the absence of a control group, and the inclusion of both male and female swimmers in this study may have affected the findings.

## 5. Conclusions

The swimmers improved their performance time in middle-distance events as well as their biomechanical variables in the corresponding distances in both Year-1 and Year-2 after a 12-week mesocycle training period. Moreover, the swimmers increased their HG but not ISO and TF. The strength asymmetries calculated by dryland (ISO and HG) and in-water (TF) tests were not different within two subsequent years when the swimmers applied a similar content, volume, and intensity of training. Increased biological maturity may affect the dryland strength gains in swimmers but does not affect the upper limb asymmetry index.

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