

# Scapular-Muscle Performance: Two Training Programs in Adolescent Swimmers

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**Context:** Swimming requires well-balanced scapular-muscle performance. An additional strength-training program for the shoulders is pursued by swimmers, but whether these muscle-training programs need to be generic or specific for endurance or strength is unknown.

**Objective:** To evaluate isokinetic scapular-muscle performance in a population of adolescent swimmers and to compare the results of training programs designed for strength or muscle endurance.

**Design:** Controlled laboratory study.

**Setting:** University human research laboratory.

**Patients or Other Participants:** Eighteen adolescent swimmers.

**Intervention(s):** Each participant pursued a 12-week scapular-training program designed to improve either muscle strength or muscle endurance.

**Main Outcome Measure(s):** Bilateral peak force, fatigue index, and protraction/retraction strength ratios before and after the scapular-training program.

**Results:** Scapular protraction/retraction ratios were slightly higher than 1 (dominant side = 1.08, nondominant side = 1.25,  $P = .006$ ). Side-to-side differences in retraction strength were apparent both before and after the training program ( $P = .03$  and  $P = .05$ , respectively). After the training program, maximal protraction ( $P < .05$ ) and retraction ( $P < .01$ ) strength improved on the nondominant side. Peak force and fatigue index were not different between the training groups. The fatigue indexes for protraction on both sides ( $P < .05$ ) and retraction on the nondominant side ( $P = .009$ ) were higher after the training program.

**Conclusions:** We describe the scapular-muscle characteristics of a group of adolescent swimmers. Both muscle-strength and muscle-endurance programs improved absolute muscle strength. Neither of the strength programs had a positive effect on scapular-muscle endurance. Our results may be valuable for coaches and physiotherapists when they are designing exercise programs for swimmers.

**Key Words:** upper extremity, strength training, endurance training, athletes

## Key Points

- We describe sport-specific adaptations regarding scapular-muscle performance in adolescent swimmers. Increased protraction strength and side-to-side differences were observed.
- In these athletes, both strength-training and muscle-endurance programs improved scapular-muscle strength, but neither program improved scapular-muscle endurance.
- Addressing muscle imbalances and asymmetry may be important to preventing injury in adolescent swimmers.

Swimming is a demanding sport, especially with respect to the shoulder joint. Shoulder injuries frequently occur in swimming athletes: 47% to 80% of all competitive swimmers reported shoulder injuries during their sport careers.<sup>1–3</sup> Swimming requires many sequential repetitive movements, with little opportunity for rest. An elite swimmer performs approximately 2500 shoulder revolutions during each training session. Consequently, sufficient upper limb muscle endurance and strength are necessary in these athletes.

The scapular muscles have an important function in swimming.<sup>4–6</sup> Electromyographic stroke analysis shows that the serratus anterior muscle has the leading function,<sup>4</sup> being continuously active throughout the stroke and positioning the scapula for hand entry, hand exit, and pulling the body over the arm. As a result, the serratus anterior may be susceptible to fatigue. An appropriate upward rotation of the scapula is necessary to avoid impingement during the swimming stroke. Considering the cooperation between the serratus anterior and lower

trapezius muscles in scapular upward rotation,<sup>7</sup> the lower trapezius is also of importance in swimming.<sup>5,6</sup>

The function of the scapular muscles in swimming has already been examined by several authors.<sup>5,6</sup> In 2004, Su et al<sup>6</sup> compared isometric strength values of the scapular muscles in swimmers before and after a single swim session. Serratus anterior and upper trapezius strength decreased by 14% and 13%, respectively. Fatigue of the scapular muscles may influence other factors, such as muscle activity and kinematics. A few researchers<sup>8,9</sup> examined the effect of serratus anterior fatigue on muscle-activation timing and scapular kinematics. After a fatigue protocol for the serratus anterior, muscle activation was greater in the upper trapezius, which can compensate for serratus anterior fatigue. The scapular kinematics after serratus anterior fatigue were characterized by decreased posterior tilting and increased internal rotation. Alterations in both muscle activation and scapular kinematics may contribute to shoulder injuries, including subacromial impingement syndrome and glenohumeral joint instability.<sup>10–12</sup> In

patients with subacromial impingement, decreased serratus anterior activity and increased anterior tipping and internal rotation were found.<sup>12</sup>

Because of the increased need for muscle endurance and the considerable risk for shoulder injuries, swimmers may benefit from a specific shoulder-training program. However, evidence about the most effective way of training (for instance, muscle-strength versus muscle-endurance training) is lacking. In the literature, strength programs have focused primarily on the glenohumeral muscles and on maximal strength to improve sport performance.<sup>13–17</sup> One group<sup>18</sup> examined the effect of a functional strength program, with selected exercises for the rotator cuff and serratus anterior, on the incidence of shoulder pain. For the serratus anterior only, an endurance program (3 sets until exhaustion) was followed; for the other muscles, 3 sets of 10 repetitions were completed. However, in the strength evaluation, only maximal strength was measured. An endurance-specific measurement, such as the fatigue index (FI), was not investigated. Thus, no conclusions about muscle endurance could be made. With respect to the available literature on strength training in swimmers, whether programs should focus on maximal strength or on muscle endurance is unknown.

We had several goals for our study. First, we evaluated the isokinetic muscle performance of the scapular muscles in adolescent swimmers by assessing peak force and the FI during an isokinetic protraction-retraction protocol. Second, we compared muscle strength and muscle endurance before and after a strength- or endurance-training program in order to determine whether shoulder muscle-training programs in swimmers need to be specific for muscle strength or endurance. Third, we measured side-to-side differences in strength before and after the training program. To our knowledge, this investigation has never been performed before in adolescent swimmers.

## METHODS

### Participants

A total of 18 adolescent swimmers (11 females, 7 males) participated in our study. All athletes were members of the same swimming club and had 4 to 6 training sessions every week with a mean session duration of 2 hours. The age of participants was  $14.7 \pm 1.3$  years; participant height was  $165.2 \pm 8.3$  cm, and mass was  $50.06 \pm 9.13$  kg. Two swimmers were left handed; the others were right handed. All athletes breathed on both sides while swimming. Exclusion criteria were cervical or thoracic conditions, previous shoulder surgery, or shoulder pain that interfered with swim training. None of the swimmers experienced any shoulder pain during the 12-week test period. Before participating in this study, the swimmers and their parents signed informed consent documents. This study was approved by the ethical committee of Ghent University.

### Design

This study was a 2-group, randomized design with repeated measures. Between the 2 strength and endurance measurements, the volunteers followed a scapular-training schedule of 3 times per week for 12 weeks. The training program was completed before the athletes started swim

training each day. All athletes participated in their normal swim practices and races.

### Isokinetic Protraction-Retraction Strength Evaluation

Isokinetic testing is considered the “gold standard” in terms of objectively evaluating an athlete’s strength.<sup>19–22</sup> Cools et al<sup>20,21</sup> developed a reliable isokinetic protraction-retraction protocol (intraclass correlation coefficient = 0.88–0.77) in healthy volunteers that was used successfully in athletes.

All isokinetic tests were performed using an isokinetic dynamometer (System 3; Biodex Medical Systems, Inc, Shirley, NY). For isokinetic strength measurement of the scapular muscles, we used the closed chain attachment, which was fixed horizontally to the dynamometer. We followed the same testing procedures and testing positions described by Cools et al.<sup>20,21</sup> Each swimmer performed 2 isokinetic tests on both sides, the first test at a linear speed of 12.2 cm/s (5 repetitions at an angular velocity of 60°/s) and the second test at 36.6 cm/s (40 repetitions at an angular velocity of 180°/s). The resting period between tests was 10 seconds. The first test determined maximal strength, and the second test evaluated muscle endurance. The test started in a maximal retracted position, and participants were instructed to perform maximal protractions followed by retraction movements over the total range of motion. Because movement took place in the horizontal plane, gravity correction was not performed. Before starting data collection, each volunteer performed 5 familiarization trials. During the test, the swimmers were given only verbal encouragement and no visual feedback from the computer screen. The testing sequence was the same for both groups and both sets of measurements.

### Scapular-Training Program

Swimmers were randomly allocated to either the muscle-strength group or the muscle-endurance group. The training program was supervised by a physiotherapist and completed in a gym room near the swimming pool. Exercises were the same for both groups, but training weights and number of repetitions were different so that we could focus on either muscle strength or muscle endurance. Each session consisted of 4 exercises, the first 2 of which were designed to reinforce the serratus anterior muscle and remaining 2 of which were designed for the entire trapezius muscle.<sup>23–25</sup> The schedule was designed to train both muscle groups alternately and was the same for both groups and sessions. We selected the exercises based on previous experimental studies.<sup>23–26</sup> If possible, exercises were performed in the lying position rather than in the standing or sitting position because the supine and prone positions are more sport specific for swimmers. The first exercise (Figure 1) was a variant of the dynamic hug movement,<sup>23</sup> which can be described as horizontal flexion of the humerus, starting at 60° of elevation. The swimmer crossed his or her hands while holding an elastic exercise band. Next, the swimmer performed scapular protraction by moving the hands away from each other. Different-colored exercise bands were used to determine the most suitable amount of resistance. In the second exercise (Figure 2), the swimmer performed an elbow push-up.<sup>24</sup> With both elbows flexed to 90° and upper extremity weight



Figure 1. Dynamic hug movement.

supported by the elbows, full protraction was accomplished. This exercise is a variant of the normal push-up exercise described by Ludewig et al.<sup>24</sup> The exercise was performed on both feet (muscle-strength group) or both knees (muscle-endurance group). The third exercise (Figure 3) was intended for the lower part of the trapezius muscle.<sup>26</sup> While lying on his or her side, the swimmer performed glenohumeral external rotation with a dumbbell. The last exercise (Figure 4) started in the prone position, with both shoulders abducted to 90° and both elbows flexed to 90°. The swimmers performed bilateral glenohumeral horizontal abduction with scapular retraction using 2 dumbbells. The entire muscle (all 3 parts) is active during this exercise.<sup>25</sup>

We determined the 2 training programs based on the clinical literature.<sup>27,28</sup> The strength group trained at a 10-repetition maximum and performed 3 sets of 10 repetitions, whereas the endurance group trained at a 20-repetition maximum and performed 3 sets of 20 repetitions. Weights were reevaluated and adapted after 6 weeks.

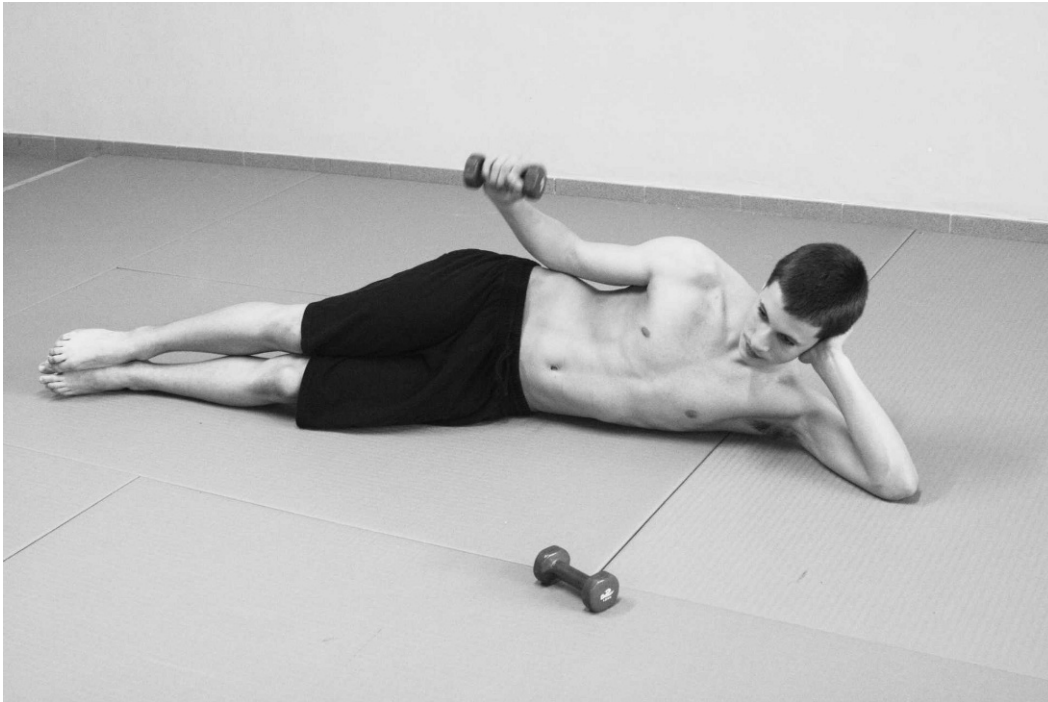
### Data Analysis

We used Biodex software to determine peak force. In addition, we determined protraction/retraction ratios and the FI. The protraction/retraction ratio, with the protraction value as agonist, was calculated based on peak-force data. From the endurance test (40 repetitions), the FI was calculated for further analyses. The FI (percentage) is a ratio of the difference in output during the first and third portions of the test. Negative values indicate that the output in the last third of the test has increased compared with the first third, and positive values represent a decline in output. Peak force during protraction and retraction at low velocity (12.2 cm/s), the strength ratio, and the FI were the dependent variables.



Figure 2. Elbow push-up.





**Figure 3. External glenohumeral rotation.**

We used the Shapiro-Wilcoxon test to control data distribution. In this study, all data were normally distributed with equal variances, so parametric tests were appropriate for further analyses. To analyze anthropometric group differences, an independent *t* test with  $\alpha = .05$  was used. No age, mass, or height differences between groups were noted (all *P* values  $> .05$ ).

We used a general linear model (GLM) 3-way analysis of variance (ANOVA) with repeated-measures design for statistical analysis. The within-subjects factors were time (pretest, posttest) and side (dominant, nondominant). Group (muscle strength or muscle endurance) was the between-subjects factor. We were interested in interaction effects of time and group, as well as main effects. In the presence of a significant interaction, post hoc Bonferroni *t* tests were performed. In this study,  $\alpha$  was set at .05, and the corrected  $\alpha$  was set at .025. All statistical analyses were performed with SPSS (version 15.0; SPSS Inc, Chicago, IL). Power analysis of the strength and endurance values was calculated at 67%.

## RESULTS

### Peak Force

Descriptive data and results from the post hoc Bonferroni adjustments for peak force regarding time (pretraining versus posttraining), group (strength versus muscle endurance), side (dominant versus nondominant), and both movement directions (protraction and retraction) are summarized in Table 1.

The GLM 3-way ANOVA for repeated measures revealed no triple interaction effect for time  $\times$  side  $\times$  group for protraction or retraction peak force. Furthermore, we found no 2-way interaction effects for group (time  $\times$  group or side  $\times$  group) for protraction or

retraction peak force. Finally, none of the between-subjects tests for group were significant for protraction ( $P = .60$ ) or retraction ( $P = .50$ ) peak forces. These results indicate no significant effect of training group.



**Figure 4. Horizontal abduction with scapular retraction.**

**Table 1. Peak Force (at 12.2 cm/s) and Post Hoc Results for Protraction and Retraction by Time, Side, and Group (Mean ± SD)**

| Motion      | Time         | Dominant Side                   |                                |                       | Nondominant Side        |                        |                             | P Value for Side | P Value for Time   |
|-------------|--------------|---------------------------------|--------------------------------|-----------------------|-------------------------|------------------------|-----------------------------|------------------|--------------------|
|             |              | Strength-Training Group (n = 9) | Muscle-Endurance Group (n = 9) | Entire Group (N = 18) | Strength-Training Group | Muscle-Endurance Group | Entire Group                |                  |                    |
| Protraction | Pretraining  | 206.61 ± 76.09                  | 222.18 ± 97.22                 | 214.40 ± 85.07        | 200.52 ± 69.07          | 224.01 ± 82.55         | 212.31 ± 74.81              | NA               | NA                 |
|             | Posttraining | 234.97 ± 86.31                  | 256.31 ± 103.98                | 245.64 ± 93.53        | 225.68 ± 89.07          | 243.34 ± 76.62         | 234.51 ± 81.11              | NA               | NA                 |
| Retraction  | Pretraining  | 188.36 ± 59.45                  | 212.52 ± 101.23                | 200.44 ± 81.48        | 162.58 ± 57.53          | 184.35 ± 76.14         | 137.47 ± 66.42 <sup>a</sup> | .030             | <.001 <sup>b</sup> |
|             | Posttraining | 220.98 ± 64.77                  | 222.80 ± 56.61                 | 221.89 ± 59.02        | 236.06 ± 59.72          | 262.88 ± 76.47         | 249.47 ± 67.97 <sup>a</sup> | .050             | <.001 <sup>b</sup> |

Abbreviation: NA, no post hoc test completed because main effects were present.

<sup>a</sup> Significant results.

<sup>b</sup> Significant 2-way interaction for group × side.

For protraction peak force, no 2-way interactions for time × side were noted ( $P = .5$  and  $P = .8$ , respectively). However, a main effect was seen for time on protraction peak force ( $P = .037$ ). Thus, time effects were present equally on both sides and in both groups, and posttraining differences were independent of group and side. Therefore, post hoc analysis on these variables was not performed.

For retraction peak force, a time × side interaction was demonstrated ( $P = .005$ ). Based on post hoc pairwise comparisons with Bonferroni correction for retraction, peak force on the nondominant side was higher posttraining ( $P < .001$ ). No other post hoc pairwise comparisons were significant.

**Protraction/Retraction Ratio**

The GLM 3-way ANOVA for repeated measures revealed no triple interaction effect for time × side × group for the protraction/retraction ratio ( $P = .7$ ). Additionally, we found no 2-way interactions for group (time × group or side × group;  $P = .8$  and  $P = .9$ , respectively) or between-subjects main effects for group ( $P = .92$ ).

For the protraction/retraction ratio, the GLM showed a dual time × side interaction ( $P = .002$ ). Using the post hoc test, we noted side-to-side differences at both test moments ( $P = .006$  and  $P = .024$ , respectively). With respect to time differences, the ratio on the nondominant side was lower posttraining ( $P < .001$ ) (Table 2).

**Fatigue Index**

No 3-way interaction for time × side × group was revealed by the GLM for the protraction and retraction FIs ( $P = .075$  and  $P = .90$ , respectively). Additionally, no 2-way interactions for group (time × group or side × group) were found for the protraction ( $P = .6$  and  $P = .075$ ,

respectively) or retraction ( $P = .67$  and  $P = .57$ , respectively) FIs, and no significant between-subjects results for group ( $P = .45$  and  $P = .51$ , respectively) were present (Table 3).

No interaction effects were found for the protraction FI. However, the GLM showed a main effect for time ( $P = .003$ ). The FI was greater posttraining, with increases in all values. A positive FI indicates less muscle endurance. For the retraction FI, a time × side interaction effect was demonstrated ( $P = .037$ ). Using post hoc analysis, we found a training (time) effect on the nondominant side ( $P = .009$ ). The FI was increased on the nondominant side posttraining.

**DISCUSSION**

Our purpose was to describe the profile of isokinetic scapular-muscle performance in a population of healthy adolescent competitive swimmers. Additionally, we wanted to verify the effect of 2 types of strength program on scapular-muscle strength in swimmers. Our study provides important information related to scapular-muscle training and adaptations in competitive swimmers.

**Swimmers' Muscle Performance**

Based on pretraining results, we offer a scapular-strength profile of adolescent swimmers. Regarding the peak force data, at low velocity our swimmers were stronger in protraction than in retraction movements. This increased protraction strength may be the result of a sport-specific adaptation. Previous researchers<sup>4</sup> showed continuous activity of the serratus anterior muscle. Because of the higher protraction peak force in our swimmers, the protraction/retraction ratio was greater than 1. Among healthy adults not active in overhead sports, the protraction/retraction ratio is approximately 1, meaning that both

**Table 2. Protraction/Retraction Ratio (at 12.2 cm/s) and Post Hoc Results by Time, Side, and Group (Mean ± SD)**

| Protraction/Retraction Ratio | Dominant Side                   |                                |                       | Nondominant Side        |                        |                          | Post Hoc Results |                                     |
|------------------------------|---------------------------------|--------------------------------|-----------------------|-------------------------|------------------------|--------------------------|------------------|-------------------------------------|
|                              | Strength-Training Group (n = 9) | Muscle-Endurance Group (n = 9) | Entire Group (N = 18) | Strength-Training Group | Muscle-Endurance Group | Entire Group             | P Value for Side | P Value for Time (Nondominant Side) |
| Pretraining                  | 1.09 ± 0.23                     | 1.07 ± 0.14                    | 1.08 ± 0.19           | 1.23 ± 0.14             | 1.27 ± 0.35            | 1.25 ± 0.26 <sup>a</sup> | .006             | NA                                  |
| Posttraining                 | 1.06 ± 0.28                     | 1.09 ± 0.33                    | 1.08 ± 0.30           | 0.94 ± 0.28             | 0.92 ± 0.15            | 0.93 ± 0.22 <sup>a</sup> | .024             | <.001                               |

Abbreviation: NA, no post hoc test completed because main effects were present.

<sup>a</sup> Significant 2-way interaction for group × side.

<sup>b</sup> Significant results ( $P < .025$ ).

**Table 3. Fatigue Index and Post Hoc Results for Protraction and Retraction (at 36.6 cm/s) for Side, Group, and Time (Mean ± SD)**

| Fatigue Index | Time         | Dominant Side                   |                                |                       | Nondominant Side        |                        |                            | P Value for Side | P Value for Time  |
|---------------|--------------|---------------------------------|--------------------------------|-----------------------|-------------------------|------------------------|----------------------------|------------------|-------------------|
|               |              | Strength-Training Group (n = 9) | Muscle-Endurance Group (n = 9) | Entire Group (N = 18) | Strength-Training Group | Muscle-Endurance Group | Entire Group               |                  |                   |
| Protraction   | Pretraining  | 1.36 ± 29.27                    | -14.7 ± 59.51                  | -6.67 ± 44.22         | -32.33 ± 43.96          | 3.43 ± 20.19           | -14.45 ± 37.90             | NA               | NA                |
|               | Posttraining | 10.8 ± 17.18                    | 15.16 ± 11.75                  | 12.98 ± 14.45         | 13.25 ± 20.89           | 15.48 ± 12.50          | 14.37 ± 16.74              | NA               | NA                |
| Retraction    | Pretraining  | -3.01 ± 16.17                   | 2.12 ± 21.18                   | -0.44 ± 18.40         | -23.72 ± 44.36          | -11.45 ± 45.94         | -17.58 ± 4.26 <sup>a</sup> | .089             | .009 <sup>b</sup> |
|               | Posttraining | 4.86 ± 19.99                    | 6.36 ± 20.60                   | 5.61 ± 19.70          | 10.85 ± 19.82           | 16.75 ± 19.60          | 13.80 ± 1.93 <sup>a</sup>  | .071             | .009 <sup>b</sup> |

Abbreviation: NA, no post hoc test completed because main effects were present.

<sup>a</sup> Significant results.

<sup>b</sup> Significant 2-way interaction for group × side.

muscle groups are equal in strength.<sup>20</sup> In a study of adolescent gymnastic athletes,<sup>21</sup> ratios of 1.24 and 1.35 were found. This population is comparable to our group of swimmers, given the serratus anterior dominance in both gymnastics and swimming and the bilateral use of the upper extremities. However, the control group of gymnasts also showed ratios that were higher than the standard value of 1 (range, 1.20–1.21). Cools et al<sup>21</sup> suggested that the higher ratios might be related to adolescent muscle characteristics and not to sport-specific adaptations.

Furthermore, values greater than 1 were also noted in other athletes,<sup>7,10,11</sup> so muscle balance may favor a specific sport. Therefore, comparisons of muscle balance should be made within each sport and not with the 1:1 value found in nonathletes. The question arises as to whether this altered muscle balance might be an adaptation only or a possible injury risk factor. Prospective studies of larger groups of athletes are needed to identify possible risk factors, such as muscle balance.

In addition to evaluating muscle strength, we investigated muscle endurance. We used the FI to measure the degree of muscle fatigue after 40 repetitions. During the pretraining test, the FI values were all negative. This means that the endurance test resulted in increased work between the first third and last third of the 40 repetitions. The swimmers had good muscle-endurance capacity, which is a positive result. However, the large SDs indicate much intersubject variability. Compared with a previous study<sup>21</sup> of gymnasts and a control group of nonathletic adolescents performing the same protocol, the swimmers had more muscle endurance. Increased muscle endurance might be a sport-specific adaptation in swimmers, although further research is necessary to exclude other possible factors, such as the specificity of the protocol.

Swimming is considered a symmetric sport, but side-to-side differences in strength are reported in the literature. Several authors<sup>29,30</sup> found side-to-side differences in isokinetic glenohumeral rotational strength in swimmers. Values were significantly higher for external-rotation strength in the dominant shoulder. We also noted side-to-side differences, with significant results for retraction. A unilateral breathing pattern during freestyle may explain this phenomenon. When breathing to one side, the contralateral side must stabilize the body, which requires a good deal of muscle activity. However, many swimmers are bilateral breathers. In these athletes, the effects of arm dominance in daily activities could be responsible for side-to-side differences. Regarding the important function of the trapezius muscle in scapular stability,<sup>7</sup> side-to-side

differences in strength can lead to scapular asymmetry. Thus, for injury prevention in swimmers, achieving bilateral symmetry may be very valuable. With respect to muscle endurance, some side-to-side differences were present, with muscle endurance lower on the dominant side. From a clinical point of view, it may be important to enhance symmetry rather than muscle endurance.

### Evaluation of Training Programs

**Group Differences.** We found no group differences for any evaluated factors. Strength training and muscle-endurance training seemed to have similar effects on swimmers' strength improvement. In his classic 1945 work, Delorme<sup>28</sup> suggested that a resistance-training program using a low number of repetitions and high resistance favors adaptations in strength, whereas training with a high number of repetitions and low resistance increases muscle endurance. In a more recent study, Campos et al<sup>31</sup> compared 3 different modalities of lower extremity strength training in healthy young men. Maximal strength and muscle endurance were measured before and after a training program. One group performed 4 sets of 3- to 5-repetition maximums, the second group performed 3 sets of 9- to 11-repetition maximums, and the third group performed 2 sets of 20- to 28-repetition maximums. They found an overall significant improvement in maximal strength, similar to our results. However, muscle endurance increased significantly only in the group performing the greatest number of repetitions. This finding contrasts with the present results, but we should note that our test population and the muscles examined in this study were different. The additional swimming training in our study could be an important factor as well and might explain some differences between our results and those of Campos et al.<sup>31</sup> Hagberg et al<sup>32</sup> compared isometric shoulder-strength training with isometric shoulder-endurance training in women with neck and shoulder pain. Shoulder-endurance training was less successful than strength training in improving muscle endurance. The authors recommended strength training in addition to shoulder-endurance training rather than endurance training alone. Yet the study focused only on women with neck and shoulder pain, making comparisons with our swimmers difficult.

Another factor is the different number of repetitions between the test (40) and training situations (20) in our investigation. For a sport-specific approach, we might consider an alternative training modality. This has already been suggested by Van Heuveln,<sup>33</sup> who concluded that



stroke rates in swimming could be the basis for a strength program. A 100-m freestyle swimmer performs about 50 strokes during his race; therefore, the number of repetitions during strength training should also be 50. However, this proposal has not yet been investigated.

**Time Differences.** For protraction, we noted a main effect of training, indicating that peak forces for the protractors were higher after training. Still, given the dominant role of the serratus anterior<sup>4</sup> in swimming, it is unclear whether the improvement resulted from the strength program alone or a combination of the strength program and swimming-training sessions. An additional study with a control group performing complete swimming training would be useful. For retraction, strength increased only on the nondominant side. Because the trapezius muscle is not a major source of propulsion force<sup>4</sup> in swimming, it is very likely that strength training caused this increase. Asymmetry could explain these findings. At the start of the study, the nondominant side was slightly weaker. Considering that the same amount of weight and number of repetitions were used bilaterally, we would expect strength to increase more on the weaker side.

Neither of the training programs had a positive influence on muscle endurance. All FIs became positive, demonstrating less muscle endurance in our test population after 12 weeks of swimming combined with a strength-training or muscle-endurance program. In terms of injury prevention, decreased muscle endurance is not a desirable outcome. Fatigue of the scapular retractor muscles may lead to additional protraction, which can result in anterior translation of the humeral head, narrowing of the subacromial space, and impingement.<sup>6,34</sup> Furthermore, fatigue of the serratus anterior muscle may restrict upward scapular rotation in swimmers, which also increases the risk of impingement.<sup>5,6</sup> The decreased muscle endurance we noted may be from the swimming training; it is likely that swimming training causes fatigue in both the serratus anterior and trapezius. We suggest that 12 weeks of intensive swimming training caused fatigue in the scapular muscles, resulting in less muscle endurance. Su et al<sup>6</sup> demonstrated fatigue after a single training session, which supports our hypothesis. Our findings indicate the importance of preventing scapular muscle fatigue in programs for injury prevention. However, the training program modality should be further explored. Beach et al<sup>30</sup> found a strong negative correlation between isokinetic muscle-endurance values and shoulder pain in swimmers. Swimmers with low levels of muscle endurance had shoulder pain, although we must recognize that Beach et al examined the glenohumeral rotator muscles, whereas we studied the scapular muscles, and used a test protocol of 50 repetitions at 240°/s, compared with our protocol of 40 repetitions at 160°/s.

Protraction/retraction ratios were altered as a result of the training program. Compared with pretraining testing, the strength ratio remained the same for the dominant side but decreased on the nondominant side. Increased peak force for retraction on the nondominant side explains the altered protraction/retraction ratio. Overall, these ratios can be considered satisfactory because of the absence of large muscular imbalances.

After the training period, trapezius muscle strength was more symmetric, which may be valuable in terms of injury prevention. In a bilateral sport such as swimming,

achieving a greater degree of left to right symmetry may be particularly important.

**Limitations.** Care should be taken when attempting to generalize our results. The swimmers were team members of equal swimming levels and ages, making comparisons possible. However, these results are very specific for the defined swimming-level and age groups. An older or more experienced population may show more and different sport-specific adaptations. Further research with respect to swimming level and age would be beneficial to investigate these factors.

Also, the testing position during isokinetic evaluation may need to be addressed. The swimmer sat with the arm elevated in the scapular plane, which is not a swimming-specific position. Because about 80% of swimming practice time is spent performing freestyle, a prone testing position may be more suitable for swimmers.<sup>30</sup> Falkel et al<sup>35</sup> found that this test position provided useful results for isokinetic glenohumeral rotation in swimmers: swimmers' shoulder strength was greater in the prone position than in the supine position ( $P < .05$ ).<sup>35</sup> Thus, this position may also result in higher values for the scapular muscles. However, further research is necessary to investigate the influence of different testing positions.

Our study was focused on muscle strength and endurance only in the shoulder area. Therefore, we did not consider some other factors involved in swimming. For example, we did not take into account other links of the kinetic chain. The kinetic chain principle describes how the human body can be considered as a series of interrelated links or segments.<sup>7</sup> Swimming requires whole-body activation, so the concept of the kinetic chain might be very important in this sport. Core stability especially may be essential in swimming to maintain stability in water. Additional studies examining other parts of the kinetic chain will provide further descriptions of swimmers' characteristics.

Finally, the absence of a control group can be considered a limitation. Whether these results are specific to the swimming population or characteristic of adolescents in general is unknown.

## CONCLUSIONS

This study represents one of the first steps in the description of sport-specific adaptations in the scapular-muscle performance of young swimmers. Scapular-muscle performance was characterized by increased protraction strength and side-to-side differences. Further research is necessary to determine whether these adaptations increase injury risk. After finishing the scapular-training program, muscular balance and side-to-side symmetry were altered. On the nondominant side, the protraction/retraction ratio decreased to 0.93 (compared with 1.23 before training). The side-to-side differences in retraction force noted initially were not present at the posttraining test. Less muscular imbalance and more left-to-right symmetry can be considered important issues in preventing injuries among swimmers. However, after 12 weeks of concurrent swimming and strength training, muscle endurance was less than before training. The finding that muscle endurance was not improved by our training program may be the result of exhaustion, either as a consequence of swimming

training itself or in combination with strength training. Collecting more information concerning sport-specific adaptations in swimmers is the first goal in further research.

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