

# Swimming Practice and Scapular Kinematics, Scapulothoracic Muscle Activity, and the Pressure-Pain Threshold in Young Swimmers

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**Context:** Whereas alterations in scapular kinematics, scapulothoracic muscle activity, and pain sensitivity have been described in adult swimmers, no researchers have examined these outcomes in young swimmers.

**Objectives:** To compare scapular kinematics, scapulothoracic muscle activation, and the pressure-pain threshold (PPT) of the shoulder muscles among young nonpractitioners (those who were not involved in sports involving the upper limbs), amateur swimmers, and competitive swimmers.

**Design:** Cross-sectional study.

**Setting:** Laboratory.

**Patients or Other Participants:** A total of 90 individuals (age =  $11.63 \pm 0.61$  years) in 3 groups: nonpractitioners, amateur swimmers, and competitive swimmers.

**Intervention(s):** Scapular kinematics and activity of the upper trapezius, lower trapezius, and serratus anterior (SA) were measured during upper extremity elevation in the scapular plane. The PPT was assessed in the upper trapezius, infraspinatus, supraspinatus, middle deltoid, and tibialis anterior.

**Main Outcome Measure(s):** Scapular kinematics, scapulothoracic muscle activation, and PPT. We conducted a 2-way

mixed-model analysis of variance and a 1-way analysis of variance for scapular rotation and PPT, respectively. A Kruskal-Wallis test was used to assess muscle activity. The  $\alpha$  level was set at .05.

**Results:** Competitive swimmers presented more internal rotation at  $90^\circ$  ( $P = .03$ ) and  $120^\circ$  ( $P = .047$ ) and more anterior tilt at  $90^\circ$  ( $P = .03$ ) than nonpractitioners. Amateur swimmers demonstrated more anterior tilt at  $90^\circ$  ( $P = .004$ ) and  $120^\circ$  ( $P = .005$ ) than nonpractitioners. Competitive swimmers had greater SA activation in the intervals from  $60^\circ$  to  $90^\circ$  ( $P = .02$ ) and  $90^\circ$  to  $120^\circ$  ( $P = .01$ ) than amateur swimmers. They also displayed more SA activation in the interval from  $90^\circ$  to  $120^\circ$  than nonpractitioners ( $P = .04$ ). No differences were found in any of the muscles for the PPT ( $P > .05$ ).

**Conclusions:** Young competitive swimmers presented alterations in scapular kinematics and scapulothoracic muscle activation during upper extremity elevation that may be due to sport practice. Mechanical pain sensitivity was not altered in young swimmers.

**Key Words:** biomechanics, shoulder, rehabilitation, athletes

## Key Points

- Changes in scapular kinematics and scapulothoracic muscle activation occurred during upper extremity elevation in young competitive swimmers and may be caused by sport practice.
- No changes in mechanical pain sensitivity were seen for any group.

Reports on sport-related injuries in children and adolescents are increasing in the literature, as involvement in competitions has increased in this population.<sup>1,2</sup> Shoulder injuries, such as rotator cuff tears and Little League shoulders, are especially common in young overhead athletes.<sup>1,3</sup>

Swimming is very popular among children and adolescents and requires repetitive movements that place great demands on the shoulder complex.<sup>4</sup> Given the repetitive nature of swimming, changes in scapular kinematics and muscle activity may occur and predispose the swimmer to shoulder pain. Alterations in scapular kinematics and activity of the scapulothoracic muscles have been described in adult swimmers.<sup>5–7</sup>

Exercise-induced hypoalgesia has been demonstrated in some studies.<sup>8–11</sup> Recently, Stolzman and Bement<sup>11</sup> suggested that exercise may induce hypoalgesia in adolescents. If so, young swimmers may be more tolerant of pain when accomplishing their swimming tasks and predisposed to developing shoulder injuries due to overuse, as changes in upper limb mechanics may occur. However, no researchers have examined these outcomes in young swimmers.

The young population may be more likely to develop injuries due to alterations that normally occur in the body at this age.<sup>2,12</sup> Understanding the relationships among the commitment to swimming and scapular kinematics, muscle activation, and response to mechanical pain sensitivity can provide insight into the ways swimming practice alters these factors. In turn, such information can lead to more

**Table 1. Characteristics of Study Participants**

Characteristic	Group		
	Nonpractitioners (n = 30)	Amateur Swimmers (n = 30)	Competitive Swimmers (n = 30)
Sex (girls/boys)	14/16	18/12	17/13
	Mean ± SD		
Age, y	11.50 ± 1.94	11.56 ± 1.81	12.63 ± 2.02
Height, m	1.50 ± 0.11	1.46 ± 0.12	1.60 ± 0.11 <sup>a,b</sup>
Mass, kg	43.32 ± 12.19	43.33 ± 11.17	51.83 ± 9.69 <sup>a,b</sup>
Body mass index, kg/m <sup>2</sup>	18.70 ± 3.31	19.82 ± 3.33	20.04 ± 2.32
Practice experience, y	NA	4.36 ± 2.91	7.60 ± 2.61 <sup>b</sup>
Volume of swimming, m/d	NA	NA	5133.33 ± 681.44
Swimming frequency, d/wk	NA	2.00 ± 0.00	4.73 ± 0.63

Abbreviation: NA, not applicable.

<sup>a</sup> Different from nonpractitioners ( $P < .05$ ).

<sup>b</sup> Different from amateur swimmers ( $P < .05$ ).

effective evaluation and treatment of young swimmers. Therefore, the primary purpose of our study was to compare scapular kinematics and scapulothoracic muscle activation among young nonpractitioners, amateur swimmers, and competitive swimmers. The secondary purpose was to assess the pressure-pain threshold (PPT) of the shoulder muscles in the same groups. We hypothesized that alterations in all outcomes would be greater in the competitive swimmers due to swim practice.

## METHODS

### Participants

For this cross-sectional study, we invited a convenience sample of 118 children and adolescents to participate. A total of 90 male and female children and adolescents (30 nonpractitioners, 30 amateur swimmers, and 30 competitive swimmers) between 8 and 15 years of age completed the study (Table 1). Individuals were recruited by advertising at local community swim clubs and through our personal contacts to 1 of 3 groups: nonpractitioners, amateur swimmers, or competitive swimmers. *Nonpractitioners* were individuals who did not practice any sport involving the upper limbs. To be included in the amateur and competitive swimmers groups, volunteers could not participate in any other sport involving the upper extremities and had to have practiced swimming for at least 1 year, including the last year before data collection. *Amateur swimmers* were individuals who practiced a maximum of twice per week. *Competitive swimmers* were individuals who practiced at least 3 times per week, swam a minimum of 4000 m/d, had participated in professional competitive swimming for at least 1 year, including the last year before data collection, and performed freestyle as their main swimming stroke. No participants had a history of shoulder or cervical (cervical compression test and self-reported pain) dysfunction, and all had full range of shoulder elevation as evaluated by visual observation.

Exclusion criteria were cervical pain; a history of surgical stabilization or repair of the rotator cuff; a positive impingement sign (ie, Neer,<sup>13</sup> Hawkins and Kennedy,<sup>14</sup> or Jobe and Moynes<sup>15</sup> or instability tests [anterior and posterior drawer]<sup>16</sup>); a history of fracture of the clavicle, scapula, or humerus; recurrent subluxation; any systemic

disease involving the joints; any cognitive deficit that preventing the understanding of oral commands; allergy to Transpore surgical tape (3M, St Paul, MN); or body mass index (BMI) greater than 1 standard deviation from the mean according to the World Health Organization growth reference for BMI in z score for youth and adolescents.<sup>17</sup> Twenty-eight volunteers were excluded due to shoulder pain, a history of upper limb fracture, or BMI.

All participants and their parents or guardians provided written informed assent and consent, respectively, and the study was approved by the Ethics Committee on Human Research of the Universidade Federal de São Carlos.

### Instrumentation

All tests were performed on the dominant side and on a nonswimming day (ie, approximately 24 hours without practice) for the amateur and competitive swimmers. The *dominant side* was defined as the hand with which the participant drew or wrote. To measure 3-dimensional scapular kinematics, the electromagnetic tracking device Flock of Birds (MiniBird; Ascension Technology, Burlington, VT), integrated with MotionMonitor software (Innovative Sports Training, Inc, Chicago, IL), was used for data capture and analysis. The 3-dimensional scapular tracking method that we used is described elsewhere.<sup>18</sup>

We collected the activity of the upper trapezius (UT), lower trapezius (LT), and serratus anterior (SA) at a frequency of 2000 Hz per channel using the Bagnoli-8 electromyography (EMG) system (DELSYS, Inc, Natick, MA). An active double-differential surface sensor (model DE-3.1; DELSYS, Inc) of 99.9% Ag comprising 3 parallel bars with 10-mm spaces between them was attached to each muscle for data collection. The electrodes had a common mode rejection ratio of 92 dB, input impedance greater than  $10^{15}\Omega/0.2$  pF, and a preamplifier gain of  $10$  V/V  $\pm$  1%.

The sensors were attached parallel to the muscle fibers on shaved, abraded, and ethanol-cleaned skin. For the UT, the sensor was placed at the midpoint of a line between the spinous process of the C7 vertebra and the posterolateral part of the acromion.<sup>19</sup> For the LT, the sensor was placed at the midpoint between the inferior angle of the scapula and the spinous process of the T7 vertebra.<sup>20</sup> For the SA, the shoulder was abducted to 90°, and the sensor was placed on the midaxillary line at the seventh rib level.<sup>19</sup> The reference

sensor was placed over the distal ulna of the opposite wrist.<sup>21</sup> For normalization, participants performed 2 maximal voluntary isometric contractions (MVICs) for each muscle against manual resistance for 3 seconds with a 30-second interval between trials as suggested by Sousa et al.<sup>22</sup> Participants were seated upright in a chair with back support for the UT and SA trials, and the upper extremity was positioned in 90° of flexion with full elbow extension. For the UT, the individuals were instructed to elevate the extremity while the examiner (F.A.P.H.) applied manual resistance against the movement toward the floor on the distal forearm. For the SA, the participants were instructed to protract the scapula against the manual resistance that was applied to their hand in the direction of the longitudinal humeral axis. For the LT, the individuals were positioned prone with the extremity in 90° of abduction and the elbow flexed to 90° and were instructed to horizontally abduct the extremity against resistance.

We assessed the PPT using a digital algometer (model OE-220; ITO Physiotherapy & Rehabilitation, Kawaguchi-shi, Saitama, Japan). The device consists of a 1-cm<sup>2</sup> rubber disk attached to a strain gauge, which displays force (kg/cm<sup>2</sup>). The PPT was defined as the minimal amount of pressure at which the sensation changed from pressure to pain.<sup>23</sup> We assessed it over the UT (midpoint between the C7 vertebra and the posterolateral acromion), infraspinatus (muscle belly below the midpoint of the scapular spine), supraspinatus (muscle belly above the midpoint of the scapular spine), middle deltoid (muscle belly close to the inferolateral insertion), and tibialis anterior (halfway between the most superior attachment to the tibia and its tendon in the upper one-third of the muscle belly). These locations were used in a previous study.<sup>24</sup>

## Procedures

Scapular kinematics and scapulothoracic muscle activation were measured simultaneously with the participants in standing position. We instructed them to continue light fingertip contact with a flat planar surface to maintain the position of the upper extremity in the scapular plane (45° anterior to the coronal plane). They were also instructed to position their hand with the thumb pointing toward the ceiling. Three repetitions were performed. Individuals were instructed to elevate their extremity from the rest position through full range of motion, taking about 3 seconds to elevate the extremity and 3 seconds to lower it. This procedure has been shown<sup>25</sup> to be reliable during elevating and lowering of the extremity in asymptomatic individuals.

We used MATLAB software (The MathWorks, Inc, Natick, MA) for scapular kinematics and EMG data reduction. Scapular kinematics were analyzed at 30°, 60°, 90°, and 120° of upper extremity elevation. The EMG signals were sampled at 2000 Hz with a gain of 1000 and bandpass filtered at 20 to 450 Hz. The data from the 3 trials of upper extremity elevation in increments of 30° (30°–60°, 60°–90°, 90°–120°) were analyzed, and then the average of the 3 trials was analyzed. The raw data were full-wave rectified, and a seventh-order 60-Hz Butterworth notch filter was used to eliminate the noise from the electromagnetic device. We smoothed the data with MATLAB software, using a root mean square algorithm with a moving window of 500 milliseconds. In normalizing the

data, the highest EMG activity was determined in the MVIC trials, whereas the muscle activity during extremity elevation was normalized as a percentage of the MVIC.

The order of muscle assessment was randomized. Pressure was applied at a rate of 1 kgf/cm<sup>2</sup>/s. Participants were instructed to press a hand-controlled switch at the first instant when the sensation changed from pressure to pain. They completed a familiarization trial and then performed 3 trials for each muscle, with an interval of 30 seconds between trials. The mean of the 3 trials was calculated and used for the main analysis. The same-day reliability of pressure algometry has been found to be high (intraclass correlation coefficient = 0.91 [95% confidence interval = 0.82, 0.97]).<sup>26</sup>

## Statistical Analysis

The Shapiro-Wilk test was used to check the normality of the data. All variables except scapular tilt and EMG data displayed normality.

To compare the demographic data (age, height, mass, BMI) among groups, we performed a 1-way analysis of variance (ANOVA). The Bonferroni post hoc analysis was used when necessary. For years of practice and volume of swimming per day, a student *t* test was performed to compare only the amateur and competitive swimmers.

To compare scapular kinematics among nonpractitioners, amateur swimmers, and competitive swimmers, a 2-way mixed-model ANOVA was conducted for each scapular rotation, with humeral angle (30°, 60°, 90°, and 120°) as a within-subject factor and group (nonpractitioners, amateur swimmers, and competitive swimmers) as a between-subjects factor. If no interaction of group × humeral angle was observed, the main effect of group was analyzed. We used a post hoc Tukey test when needed. For scapular tilt, the nonparametric Kruskal-Wallis test for independent samples was used. The EMG activity for each muscle was analyzed separately using the Kruskal-Wallis test, considering the 3 groups and the intervals (30°–60°, 60°–90°, and 90°–120°) of upper extremity elevation. For the nonparametric tests, a post hoc Dunn test was performed when necessary. Data transformation was conducted for the first instance; however, a normal distribution was still not present.

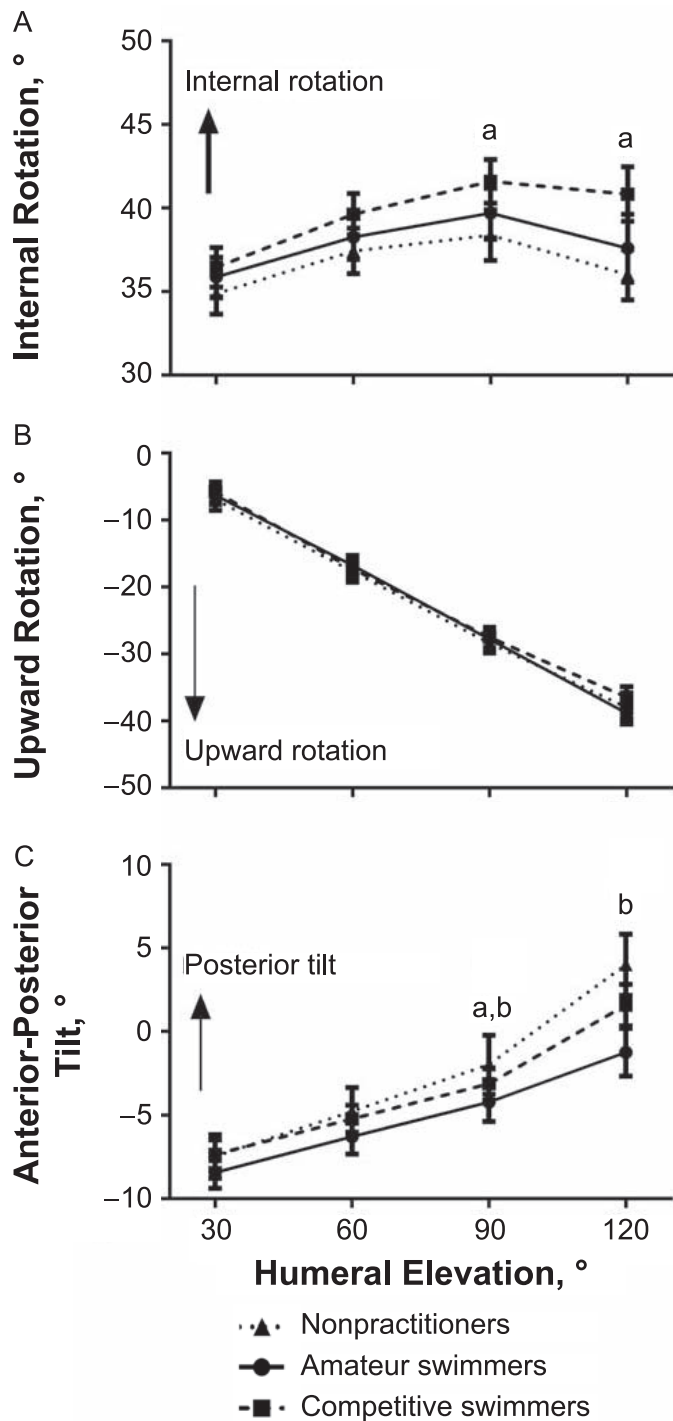
A 1-way ANOVA was used for each muscle to compare the PPT among the 3 groups. The Bonferroni post hoc analysis was used when needed.

Effect sizes between groups were calculated for differences using the Cohen *d* coefficient. An effect size greater than 0.8 was considered *large*; around 0.5, *moderate*; and less than 0.2, *small*.<sup>27</sup> All data were analyzed using SPSS (version 20; IBM Corp, Armonk, NY). We set the  $\alpha$  level at .05 for all analyses.

## RESULTS

The EMG data from 19 participants (8 nonpractitioners, 7 amateur swimmers, 5 competitive swimmers) were excluded due to noise in the signal.

We observed differences between amateur and competitive swimmers and between nonpractitioners and competitive swimmers for height ( $F_{2,87} = 9.84$ ,  $P < .05$ ) and mass ( $F_{2,87} = 5.93$ ,  $P < .05$ ; Table 1). Furthermore, differences



**Figure 1.** Scapular kinematics during upper extremity elevation in the scapular plane for, **A**, scapular internal rotation, **B**, scapular upward rotation, and **C**, scapular anterior-posterior tilt. The error bars represent the standard error of the mean. <sup>a</sup> Difference between nonpractitioners and competitive swimmers at the same angle of upper extremity elevation ( $P < .05$ ). <sup>b</sup> Difference between nonpractitioners and amateur swimmers at the same angle of upper extremity elevation ( $P < .05$ ).

were also present between amateur and competitive swimmers for years of practice ( $t_{58} = 7.37, P < .001$ ).

For scapular internal rotation, we noted an interaction of group  $\times$  humeral angle ( $F_{2,87} = 4.53, P = .01$ ), with competitive swimmers demonstrating more internal rota-

tion at 90° (mean difference = 3.22°,  $P = .03$ , Cohen  $d = 0.41$ ) and 120° (mean difference = 4.83°,  $P = .047$ , Cohen  $d = 0.56$ ) of upper extremity elevation than nonpractitioners (Figure 1A). These differences were small to moderate. No differences were demonstrated between nonpractitioners and amateur swimmers ( $P = .28$ ) or amateur and competitive swimmers ( $P = .62$ ).

We did not observe an interaction of group  $\times$  humeral angle ( $F_{2,87} = 0.17, P = .84$ ) or a main effect of group ( $F_{2,87} = 2.42, P = .11$ ) for scapular upward rotation (Figure 1B).

Differences were evident among the groups for scapular tilt, with amateur swimmers demonstrating more anterior tilt at 90° (mean difference = 2.24°,  $P = .004$ , Cohen  $d = 0.27$ ) and 120° (mean difference = 5.24°,  $P = .005$ , Cohen  $d = 0.58$ ) of upper extremity elevation than nonpractitioners (Figure 1C). Competitive swimmers also presented more anterior tilt at 90° of upper extremity elevation than nonpractitioners (mean difference = 1.15°,  $P = .03$ , Cohen  $d = 0.15$ ). These differences were small to moderate. No differences occurred between amateur and competitive swimmers ( $P > .99$ ).

For EMG activity, no differences were found among the groups for any of the angles for the UT and LT ( $P > .05$ ; Figure 2A and B).

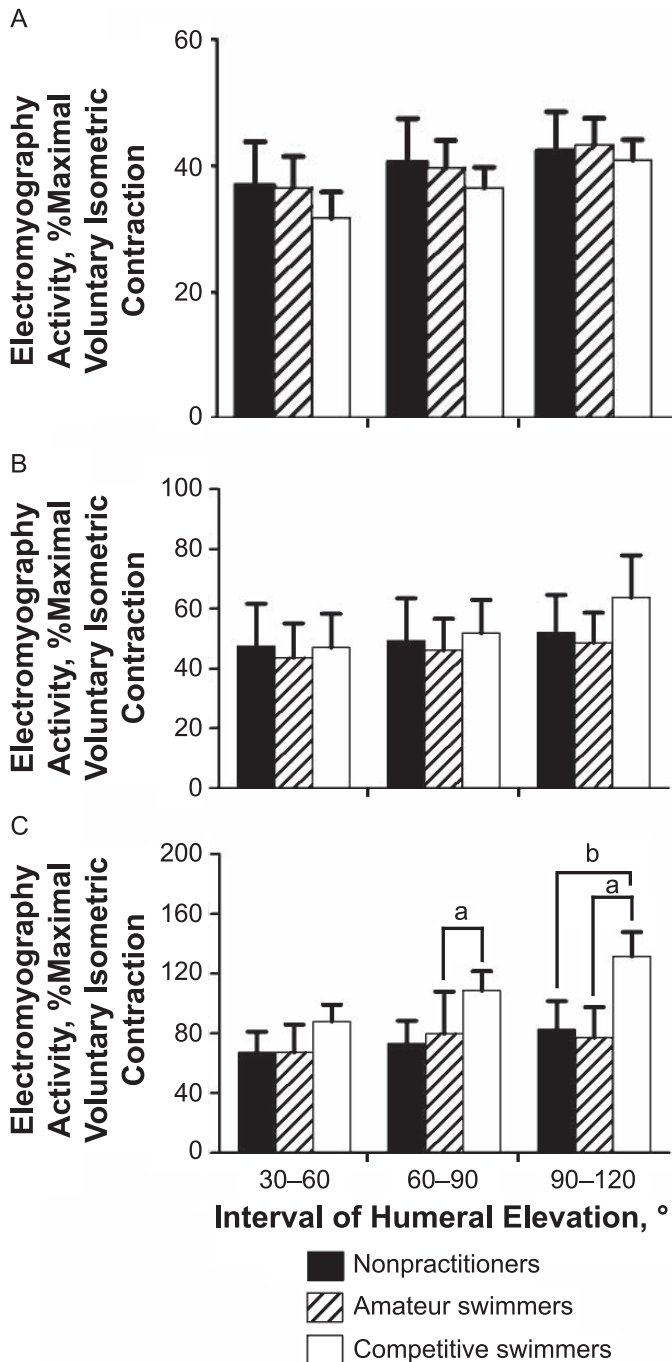
We noted a difference for the SA, with competitive swimmers showing greater activation in the intervals of 60° to 90° (mean difference = 28.8%,  $P = .02$ , Cohen  $d = 0.28$ ) and 90° to 120° (mean difference = 54.6%,  $P = .01$ , Cohen  $d = 0.60$ ) of upper extremity elevation than amateur swimmers (Figure 2C). Furthermore, competitive swimmers also had greater activation in the interval from 90° to 120° than nonpractitioners (mean difference = 49.0%,  $P = .04$ , Cohen  $d = 0.57$ ). No differences existed between nonpractitioners and amateur swimmers ( $P = .71$ ).

No differences for PPT were displayed for any of the muscles among the 3 groups ( $P > .05$ ; Table 2).

## DISCUSSION

Our study provides new information about scapular kinematics and scapulothoracic muscle activity during upper extremity elevation and the PPT in the shoulder muscles of young swimmers. In general, competitive swimmers presented more scapular internal rotation and anterior tilt and more SA muscle activity than nonpractitioners. However, the PPT was not different among groups for any of the muscles.

The freestyle stroke, which places the humerus predominantly in internal rotation<sup>5</sup> as it helps to propel the body in the water, is practiced extensively during training.<sup>4,5</sup> The repetitive nature of the strokes during swim practice may have contributed to the changes we observed in scapular kinematics during upper extremity elevation. Increased scapular internal rotation and anterior tilt may put swimmers at increased risk for shoulder pain, as these alterations have been identified in individuals with shoulder impingement.<sup>28</sup> Hibberd et al<sup>29</sup> recently demonstrated a decrease in subacromial space distance and an increase in forward shoulder posture of competitive adolescent swimmers after 6 weeks of swim training. The reduced subacromial space is believed to be associated with altered scapular kinematics.<sup>30</sup> Forward shoulder posture can be associated with pectoralis minor tightness that favors



**Figure 2.** Muscle activity (electromyography) during upper extremity elevation in the scapular plane for the, **A**, upper trapezius, **B**, lower trapezius, and **C**, serratus anterior. The error bars represent the standard error of the mean. <sup>a</sup> Difference between amateur and competitive swimmers ( $P < .05$ ). <sup>b</sup> Difference between nonpractitioners and competitive swimmers ( $P < .05$ ).

scapular anterior tilt, internal rotation, and downward rotation.<sup>31</sup> Tightness in the pectoralis minor has been identified in adult swimmers.<sup>32</sup> Despite these changes, the kinematics presented by the young swimmers may be beneficial for their swimming mechanics.

Whereas we did not analyze the anterior deltoid, this muscle is known to be highly activated during the entry of the hand in the water.<sup>5</sup> Therefore, it may be highly activated during upper extremity elevation, contributing to anterior tilt of the scapula through the reverse action. The force of the anterior deltoid causes the combined actions of scapular anterior tilt and humeral elevation. Given that the scapula may not be properly stabilized in the thorax, it cannot resist the pull of the deltoid.

The competitive swimmers also demonstrated greater activation of the SA muscle than the other groups. Considering that this muscle is a potent posterior tilter,<sup>33</sup> a possible explanation for this finding is that the SA was working against the pectoralis minor, which may have offered passive resistance during upper extremity elevation. A muscle that cooperates in upward rotation with the SA is the LT.<sup>33</sup> However, no differences were found among the groups for the LT during extremity elevation. One factor that may help to explain this finding is that competitive swimmers might have been compensating for the use of the LT by hyperactivating the SA during extremity elevation. Coordinated muscle activity is needed for synchronized joint motion and stability. The competitive swimmers in our study presented a lower LT : SA ratio based on an exploratory analysis. Although the greater SA activity may be considered a positive response to the swimming mechanics, a prospective study is needed to evaluate whether these athletes have an increased risk of developing shoulder injuries, as a lower LT : SA ratio has been identified in individuals with shoulder impingement compared with asymptomatic individuals.<sup>34</sup> We observed no differences among the groups for the UT. However, we assessed kinematics and muscle activity during upper extremity elevation. Caution should be taken when interpreting these findings, as our results would probably have differed if we had assessed a specific swimming movement.

We noted no differences in the PPT of the shoulder among the groups. In a recent study, Sacramento et al<sup>35</sup> demonstrated that children had lower PPTs in the shoulder girdle than healthy adults. Researchers<sup>8-10</sup> have shown that exercise may induce hypoalgesia, yet the amount of exposure to the exercise that is necessary to affect pain perception is not clear. Furthermore, an exploratory analysis revealed no correlation between scapular kinematics and PPT. A possible explanation for the lack of a difference in our investigation may be that the measurements were taken on a day without swimming. It may be

**Table 2.** Pressure-Pain Threshold Values for Each Group

Pressure-Pain Threshold, kgf/cm <sup>2</sup>	Group, Mean ± SD		
	Nonpractitioners (n = 30)	Amateur Swimmers (n = 30)	Competitive Swimmers (n = 30)
Upper trapezius	1.70 ± 0.70	2.06 ± 0.97	2.34 ± 1.42
Infraspinatus	2.91 ± 1.24	3.06 ± 1.40	3.64 ± 1.83
Supraspinatus	2.39 ± 1.24	2.58 ± 1.31	3.03 ± 1.78
Middle deltoid	2.37 ± 1.30	2.46 ± 1.43	2.65 ± 1.50
Tibialis anterior	5.01 ± 2.11	5.21 ± 2.23	6.45 ± 3.16

that changes can be observed immediately after swimming practice. Longitudinal studies should be conducted to determine if an alteration in the PPT predisposes athletes to changes in scapular kinematics, thereby increasing the risk of future injuries. In addition, given that we did not include individuals with shoulder pain, these findings may not be extrapolated to swimmers with a history of shoulder pain, especially persistent or recurrent pain.

Researchers should continue to investigate the adaptations and shoulder injuries that could develop over time in young swimmers. In future studies, investigators should also assess scapular kinematics and muscle activity during the swimming motion to better understand the mechanics.

## CONCLUSIONS

Competitive young swimmers presented changes in scapular kinematics and scapulothoracic muscle activation during upper extremity elevation that may be related to sport practice. Mechanical pain sensitivity was not altered in these young swimmers. This information should allow clinicians and other professionals to better understand the biomechanics of these young athletes and to anticipate and search for differences in swimmers. It may also lead to more efficient diagnostic tests and targeted treatment and preventive activities, such as dry-land training, for this population.

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