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Risk Factors Associated With Shoulder Pain and Disability Across the Lifespan of Competitive Swimmers

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Context: The prevalence of shoulder pain among competitive swimmers is high, but no guidelines exist to reduce shoulder injuries. Elucidating differences between swimmers with and without shoulder pain can serve as a basis for the development of a program to prevent shoulder injury that might lead to pain and dysfunction.

Objective: To determine whether physical characteristics, exposure, or training variables differ between swimmers with and without shoulder pain or disability.

Design: Cross-sectional study.

Setting: Multisite swimming centers.

Patients or Other Participants: A total of 236 competitive female swimmers aged 8 to 77 years.

Data Collection and Analysis: Participants completed the Penn Shoulder Score and underwent testing of core endurance, range of motion, muscle force production, and pectoralis minor muscle length and the Scapular Dyskinesis Test. Swimmers were grouped by age for analysis: ages 8 to 11 years (n = 42), 12 to 14 years (n = 43), 15 to 19 years (high school, n = 84), and 23 to 77 years (masters, n = 67). Comparisons were made between groups with and without pain and disability using independent *t* tests for continuous data and χ^2 analyses and Fisher exact tests for categorical data.

Results: Nine (21.4%) swimmers aged 8 to 11 years, 8 (18.6%) swimmers aged 12 to 14 years, 19 (22.6%) high school swimmers, and 13 (19.4%) masters swimmers had shoulder pain and disability. Differences that were found in 2 or more age groups between athletes with and without shoulder pain and disability included greater swimming exposure, a higher incidence of previous traumatic injury and patient-rated shoulder instability, and reduced participation in another sport in the symptomatic groups ($P < .05$). Reduced shoulder flexion motion, weakness of the middle trapezius and internal rotation, shorter pectoralis minor and latissimus, participation in water polo, and decreased core endurance were found in symptomatic females in single varying age groups ($P < .05$).

Conclusions: Female competitive swimmers have shoulder pain and disability throughout their lives. Given that exposure and physical examination findings varied between athletes with and without substantial pain and disability, a program to prevent shoulder injury that might lead to pain and dysfunction appears warranted and might include exposure reduction, cross-training, pectoral and posterior shoulder stretching, strengthening, and core endurance training.

Key Words: swimming, exposure variables, injury prevention

Key Points

- Competitive swimmers less than 12 years of age had substantial shoulder pain, and older swimmers had pain, dissatisfaction, and disability.
- High school swimmers were the most symptomatic and incurred the greatest load in terms of hours swum per week and per year.
- Shoulder pain, dissatisfaction, and disability were correlated positively with increased upper extremity usage in terms of swimming or water polo exposure and were correlated negatively with participation in another sport, specifically soccer for young and running or walking for mature swimmers.
- Symptomatic swimmers who were less than 12 years of age had reduced shoulder flexibility, weakness of the middle trapezius and shoulder internal rotators, and latissimus dorsi tightness, whereas symptomatic swimmers who were 12 years of age or older had pectoralis minor tightness and decreased core endurance.
- Because female competitive swimmers have shoulder pain and disability throughout their lives, a program to prevent shoulder injury that might lead to pain and dysfunction is warranted and might include exposure reduction, cross-training, pectoral and posterior shoulder stretching, strengthening, and core endurance training.

Each year, millions of people swim for exercise and recreation. Competitive swimmers might practice 5 to 7 days per week and sometimes twice daily. They have shoulder pain at a reported prevalence of 40% to 91%.[1–3] Shoulder pain can be so severe that it leads to functional impairments and termination of participation.[4] Conditions theorized to cause shoulder pain in swimmers include glenohumeral laxity, biceps or rotator cuff lesions, and impingement syndrome.[3] The incidence of rotator cuff lesions increases with age, and the cause of impingement is considered to be multifactorial. It might be due to weakness or reduced endurance of the shoulder muscles, a lack of scapular stability, poor posture, reduced flexibility, or bony alterations.[5] An injury-prevention program might help reduce the shoulder pain of swimmers, but no such program exists. To develop a prevention program, physical characteristics and exposure or training factors associated with shoulder pain must first be identified.

A relationship between *exposure,* which is defined by distance or time spent swimming, and shoulder pain exists,[3] but exposure might not be the only factor related to shoulder pain. Physical impairments found in symptomatic swimmers include reduced shoulder internal rotation strength and external rotation and abduction muscle endurance.[6,7] However, these data were collected in small, homogeneous age and training groups of swimmers. Therefore, we do not know whether deficits found in symptomatic swimmers of different training and age groups are present in swimmers across their competitive lifespans.

Over the past decade, changes have been made in competitive swimming training and equipment, such as more extensive dry-land programs and the use of redesigned paddles to improve stroke mechanics. Given these changes and the high prevalence of pain in swimmers, potentially modifiable physical characteristics of swimmers' exposure and training variables that are related to their pain need to be identified. No researchers have combined training and exposure data with physical examination findings to identify factors related to shoulder pain over an age range from the young team competitor to the master's-level swimmer. Therefore, the purpose of our study was to determine whether physical characteristics, training methods, or exposure differs between swimmers with and without shoulder pain, dissatisfaction with their shoulders, and disability over 4 age groups representing the swimmer's lifespan. Identification of factors that differentiate swimmers with and without shoulder pain could provide the basis for a program to prevent shoulder injury that might lead to pain and dysfunction.

METHODS

Participants

A total of 236 female swimmers from 8 to 77 years of age volunteered for this multicenter study. Each participant belonged to a youth, high school, or US Masters swim team. Swimmers in the Philadelphia, Pennsylvania, area were invited to participate with their coaches' approval. Adult swimmers and parents or guardians of minors provided written informed consent, and minors signed an assent form. The study was approved by the Arcardia University Institutional Review Board.

Procedures

Adult swimmers and the parents or guardians of minors completed or assisted with a survey that included demographics, questions about other sport participation, and the amount of participation in swimming on a weekly basis. They also were instructed to indicate the number of months per year they practiced and how many years they had participated in competitive swimming. Shoulder pain and dissatisfaction were assessed using the respective subscales of the Penn Shoulder Score.[8] Pain was rated at rest, with normal activities (eating, dressing, bathing), and with strenuous activities (sports, reaching, lifting) on a scale of 0 (*no pain*) to 10 (*worst possible pain*). The pain subscale total was calculated by subtracting each of the 3 scores from 10 and then adding them for a total of 0 to 30, with 30 indicating *no pain*. Disatisfaction also was assessed using the 0 (*not satisfied*) to 10 (*very satisfied*) scale. Shoulder function with swimming was measured using the Sports/Performing Arts Module of the Disabilities of the Arm, Shoulder, and Hand Outcome Measure[9] (DASH) because the sports module of the DASH has face validity for our study population, given the lack of a validated outcome measure for athletes. The DASH sports module instructs participants to rate 4 items (physical ability with sports technique, participation, satisfaction, and frequency), using a 5-point scale, with 1 indicating *no difficulty* and 5 indicating *unable* over the past week.

Next, swimmers rotated through a series of 5 stations where range of motion (ROM), strength, pectoral muscle length, core endurance, and scapular dyskinesis were assessed by members of the research team. This team consisted of an experienced physical therapist (A.T.) and 4 graduate physical therapist students (G.N.T., S.E.K., C.J., A.S.), 2 of whom were certified athletic trainers (G.N.T., S.E.K.).

Before data collection on swimmers, 2 training sessions were held in which the research team was given written instructions and practiced the testing procedures. Intrarater reliability of ROM, strength, pectoral muscle length, and scapular dyskinesis was established with 14 athletically active females (age $= 23.8 \pm 1.7$ years). *Athletically active* was defined as exercising regularly or participating in sports. Intraclass correlation coefficients (ICCs) for continuous data from strength measured by dynamometry, ROM, and pectoral length were fair to excellent (ICC [3,1] $= 0.60$ to 0.92), and percentage agreement for scapular dyskinesis and manual muscle testing was excellent ($\kappa = 0.83$ to 1.0).

Station 1: Range of Motion. Passive ROM (PROM) of both shoulders was assessed using an inclinometer for shoulder flexion in neutral rotation with the participant lying supine; shoulder flexion, with the elbow maximally flexed for long head triceps tightness[10]; shoulder flexion, with the humerus externally rotated, knees and hips flexed, and abdominal muscles actively contracted for latissimus dorsi tightness[10]; and internal and external rotation, with the shoulder abducted to 90°.

Station 2: Strength. Bilateral glenohumeral strength was assessed using a handheld dynamometer (microFET; Hoggan Industries, Draper, UT). For this study, maximal isometric force production was tested for shoulder internal and external rotation with the participant lying prone and the shoulder abducted to 90°; this position has been recommended because swimmers are familiar with it and because it is comfortable and has the highest torque values.[11] Shoulder horizontal abduction strength was measured with the participant lying prone with the elbow extended, and shoulder elevation was measured with the participant standing in the empty-can position (90° of shoulder elevation in the scapular plane and internally rotated). Two repetitions of each test were performed, and an additional repetition was performed if the difference between the first

2 measurements was greater than 1.36 kg. Arm and forearm lengths also were measured and used to calculate normalized torque values, which were obtained by multiplying the dynamometer output by the distance from the shoulder to the application of force and then dividing by body mass.

Manual muscle testing was performed bilaterally on the serratus anterior, lower trapezius, and middle trapezius muscles as described by Kendall et al.[10] Each muscle was graded categorically as normal or reduced. *Normal* was defined as no movement of the scapula when resistance was applied to the distal humerus, and *reduced* was defined as movement of the scapula with application of pressure.

Station 3: Scapular Dyskinesis. Scapular motion patterns were assessed for winging or dysrhythmia using the scapular dyskinesis test (SDT). The SDT has demonstrated reliability and validity in adult athletes participating in sports that include overhead use of the upper extremity, specifically swimming and water polo.[12,13] Shoulder flexion and abduction each were performed 5 times bilaterally with dumbbells. A 0.45-kg dumbbell was used for participants who weighed less than 36.29 kg, 1.36-kg dumbbells were used for participants who weighed from 36.29 to 68.04 kg, and 2.27-kg dumbbells were used for participants who weighed more than 68.04 kg. These weights were selected based on a pilot study in which Tate et al[14] determined that swimmers could lift the required amount safely. The examiner observed the scapulae from a posterior view and graded the motion pattern as normal or subtle dyskinesis or obvious dyskinesis.

Station 4: Endurance. Endurance of core musculature was assessed using the side bridge test (Figure 1),[15] the prone bridge test,[16] and the closed kinetic chain upper extremity stability test.[17] Participants were timed for the aforementioned tests, and a yardstick was held vertically by the tester from the mat to the lowest portion of the hip. If the hip dropped, the participant was given oral instructions to try to resume the straight position. If the hip dropped a second time, the test was ended. The participant's scapula also was monitored because loss of control resulted in winging and inability to maintain the original position. For the closed kinetic chain upper extremity stability test, 2 pieces of athletic tape were placed on a mat 36 in (91.44 cm) apart for participants more than 12 years of age and 24 in (60.96 cm) apart for younger participants. Participants assumed a push-up position with 1 hand on each piece of tape. They lifted each hand sequentially, quickly touched the opposite piece of tape, and then returned the hand to its original position. The number of repetitions in 15 seconds was recorded.[17]

Station 5: Pectoralis Minor Length. Pectoralis minor length was measured with a PALM palpation meter (Performance Attainment Associates, St Paul, MN) using surface landmarks validated by Borstad[18] (Figure 2). The following landmarks were palpated and marked by the first author (A.T.): the inferior aspect of the sternal notch and the lateral aspect of the acromioclavicular joint, which represented the clavicle length; and the medioinferior aspect of the coracoid in the deltopectoral groove, which is the proximal pectoralis minor attachment. Next, the anteroinferior aspect of rib 4 one finger-width lateral to the sternum was identified, and the swimmer was instructed to hold her index finger on the spot while the investigator measured the distance from rib 4 to the coracoid process, which represented the pectoralis minor length at rest. Next, the swimmer was instructed to elevate her upper extremity to shoulder level and flex her elbow to 90° while placing her forearm on the doorjamb. She then was instructed to twist her trunk away from her upper extremity without moving her feet until she felt a strong stretch in her pectoral muscle. A second measurement from the coracoid to rib 4 was taken and represented the length of the pectoralis minor on stretch (Figure 2).[19] Normalized pectoralis minor length at rest and on stretch was obtained by dividing the pectoral length under each condition by the clavicle length.

Figure 1. Timing for the side bridge test begins with the participant lying on her side on 1 elbow and both feet with the top foot in front and ends when her hips drop.

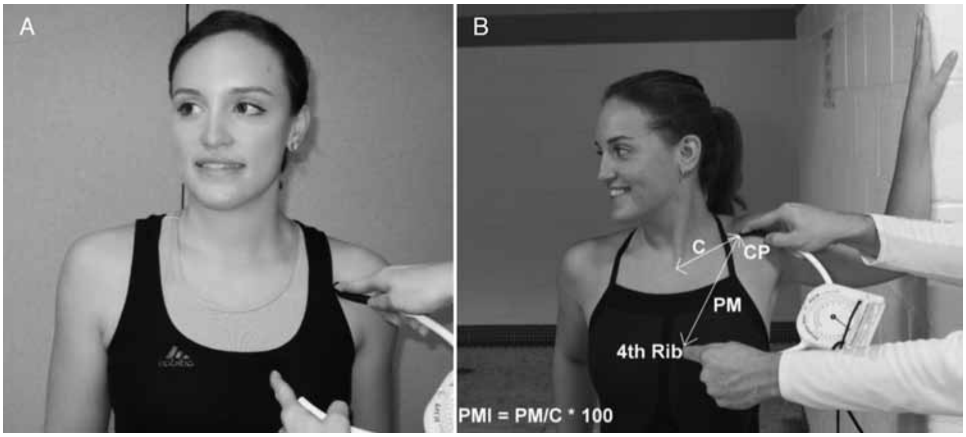

Figure 2. The pectoralis minor muscle was measured by palpating from the coracoid process to rib 4 with a PALM palpation meter (Performance Attainment Associates, St Paul, MN). A, At rest, and B, during a self-imposed corner stretch.

Data Analysis

Participants were divided into 4 groups by age, based on the similarity of hours of training and competitive level: ages 8 to 11 years (n=42), 12 to 14 years (n=43), 15 to 19 years (high school, n=84), and 23 to 77 years (masters, n=67). These groups had different swimming exposures, with respective means of 6.9 ± 2.4, 10.1 ± 4.3, 16.1 ± 6.0, and 4.0 ± 1.7 hours swum per week ($P<.001$). Cases were classified as *positive* or *negative* for substantial pain, dissatisfaction, and disability (PDD) based on the total of the Penn Shoulder Score pain scale and the satisfaction question (range, 0–40, with 40 indicating *no pain, fully satisfied*) and the total score for swimming disability using the DASH sports module (range, 4–20, with 4 indicating *no swimming disability*). For the 3 oldest groups (age>11 years), a positive case (+PDD) had to meet 2 criteria: (1) The DASH sports module score was greater than 6 points and (2) the Penn Shoulder Score was less than 35 points. For the DASH sports module, a score greater than 6 points requires the swimmer to have at least mild difficulty in 3 of the 4 areas (difficulty with usual technique, swimming because of pain, swimming as well as she would like, and spending usual amount of time practicing swimming) or moderate or severe difficulty or inability in at least 1 of the 4 areas. A Penn Shoulder Score of less than 35 points for pain and satisfaction reflects change greater than 5 points, which exceeds the total error (standard error of the mean) for the combined pain and satisfaction subscales.[8] All cases not satisfying the requirements for +PDDs were classified as –PDDs.

In the youngest group (age range, 8–11 years), only 1 of 42 swimmers fit the +PDD definition used for the older participants, which precluded further data analysis. Therefore, in the 8- to 11-year-old age group, a case was considered positive if the swimmer rated her pain equal to or greater than 2 of 10 with strenuous activity on the Penn Shoulder Score pain scale. All cases that did not satisfy the requirements for +PDDs were classified as –PDDs. For swimmers with bilateral symptoms, the data from the most painful side were used for +PDDs. For swimmers with equal pain bilaterally or no pain, the participants were listed in consecutive numeric order based on age, and alternate sides were selected.

Continuous variables for participant demographics, exposure, and physical examination were compared using independent *t* tests. Categorical variables were compared using χ^2 tests. When we found categorical variables in which 20% of the cells did not contain a minimum of 5 cases and therefore did not meet the assumption of expected cell frequency, we used a Fisher exact probability test. A 1-tailed test was used for the variables we hypothesized had a directional preference based on pilot data: history of traumatic injury, unilateral breathing pattern, and participation in water polo.[14] A 2-tailed test was used for all other variables. To determine whether stroke specialty (butterfly, backstroke, breaststroke, or freestyle) was associated with pain and disability, the data from all age groups were combined because a failure to meet minimum cell count for χ^2 occurred within each age group. We used SPSS (SPSS Inc, Chicago, IL) for data analysis.

RESULTS

The number of +PDDs was 9 of 42 (21.4%) in swimmers aged 8 to 11 years, 8 of 43 (18.6%) in swimmers aged 12 to 14 years, 19 of 84 (22.6%) in high school swimmers, and 13 of 67 (19.4%) in masters swimmers. Participant demographics for +PDDs and –PDDs are presented in Table 1. Table 2 contains quantification of swimming exposure. Table 3 contains associated categorical variables relating to sport participation and history. Table 4 contains physical examination data. All tables contain the *P* values from the respective statistical tests. Pearson χ^2 analysis comparing frequency of +PDDs and –PDDs with swimmers' reported stroke specialty (butterfly, backstroke, breaststroke, freestyle) did not reveal a difference ($\chi^2_3=2.92$, $P=.40$).

DISCUSSION

Competitive swimmers are at risk for developing shoulder pain and disability, which can lead to dissatisfaction with the use of their shoulders during swimming and daily activities. Although specific differences in swimmers with and without symptoms have been investigated extensively, we are the first to our knowledge to collectively use validated and reliable methods to test groups of swimmers poolside without expensive, labor-intensive equipment. This method has allowed

Table 1. Participant Demographics by Age Group and Case[a] (Mean ± SD)

	Age Group															
	8–11 y				12–14 y				15–19 y				Masters			
Characteristic	Negative Case	Positive Case	t	P	Negative Case	Positive Case	t	P	Negative Case	Positive Case	t	P	Negative Case	Positive Case	t_{65}	P
Participants, no.	33	9	NA	NA	35	8	NA	NA	65	19	NA	NA	54	13	NA	NA
Height, cm	144.48 ± 8.31	148.87 ± 9.91	1.35	.18	157.99 ± 13.36	166.37 ± 7.92	0.54	.10	165.63 ± 6.71	166.65 ± 6.10	0.54	.56	166.83 ± 6.86	168.33 ± 7.01	0.71	.48
Weight, kg	36.29 ± 7.01	36.48 ± 7.33	0.07	.94	48.69 ± 7.18	52.90 ± 6.51	0.40	.14	58.06 ± 7.69	58.88 ± 8.66	0.40	.69	65.42 ± 10.47	66.74 ± 12.59	0.39	.70
Body mass index	16.94 ± 2.66	16.00 ± 1.66	−1.00	.32	19.40 ± 3.77	18.63 ± 1.41	0.21	.57	20.80 ± 2.68	20.95 ± 2.82	0.21	.84	23.13 ± 3.30	23.23 ± 3.92	0.09	.92
Age, y	9.67 ± 1.29	10.11 ± 1.27	0.92	.36	13.00 ± 0.69	13.38 ± 0.74	1.43	.18	16.31 ± 1.30	16.79 ± 1.27	1.43	.16	41.72 ± 13.97	43.77 ± 12.77	0.48	.63

Abbreviation: NA, not applicable.

[a] *Case* indicates absence (negative case) or presence (positive case) of shoulder pain, dissatisfaction, and disability.

Table 2. Quantification of Swimming Exposure (Mean ± SD)[a]

	Age Group											
	8–11 y			12–14 y			15–19 y			Masters		
Swimming Exposure	Negative Case[b]	Positive Case	P	Negative Case	Positive Case	P	Negative Case	Positive Case	P	Negative Case	Positive Case	P
Time swum, y	3.48 ± 1.64	3.28 ± 1.75	.74	5.72 ± 2.10	6.56 ± 1.45	.29	7.65 ± 2.94	9.16 ± 1.80	.01	15.36 ± 13.21	22.00 ± 16.76	.13
Time swum per week, h	6.64 ± 2.17	7.83 ± 2.94	.18	9.93 ± 4.34	10.94 ± 4.36	.56	15.94 ± 6.19	16.53 ± 5.54	.71	3.78 ± 1.70	4.77 ± 1.54	.06
Time swum per year, h	189.88 ± 130.58	237.93 ± 213.62	.54	355.81 ± 262.13	396.00 ± 188.25	.69	600.30 ± 392.11	652.02 ± 302.07	.60	163.88 ± 81.22	223.60 ± 81.81	.02

[a] Indicates that t values are reported in Appendix 1.

[b] *Case* indicates absence (negative case) or presence (positive case) of shoulder pain, dissatisfaction, and disability.

Table 3. Comparison of Variables Related to History and Sport Participation Between Swimmers With and Without Shoulder Pain, Dissatisfaction, and Disability

	Age Group					
	8–11 y	12–14 y	15–19 y		Masters	
	P	*P*	*P*	χ^2_1	*P*	χ^2_1
Participation in additional organized sport teams	.03[a]	.66[a]	.51	0.44	NA	NA
Participation in specific sport or activity differing between groups	.04[a,b]	NA	.03[c]	4.93	.01[a,d]	NA
Swim paddle use	>.99[a,e]	>.99[a,e]	.44	0.59	>.99[a,e]	NA
Unilateral versus bilateral breathing pattern	.03[a]	>.99[a,e]	.10	2.76	.18	1.83
History of shoulder trauma	.21[a]	.09[a]	.04[f]	NA	.04[f]	NA
Feeling of shoulder instability	>.99[a,e]	.03[a]	.02[a]	NA	.11[a]	NA

Abbreviation: NA, not applicable.
[a] Indicates Fisher exact 2-sided test.
[b] Indicates soccer.
[c] Indicates water polo.
[d] Indicates running or walking program.
[e] Indicates that the groups compared had exactly the same frequency of condition.
[f] Indicates Fisher exact 1-sided test.

us to assess physical performance and exposure variables in competitive swimmers aged 8 to 77 years and to document the presence of shoulder symptoms throughout the lifespan of swimmers. Potential factors related to shoulder pain and disability are exposure time to swimming, training methods, and physical characteristics of the swimmers. We found that 18.6% to 22.6% of competitive swimmers in each of our 4 age groups experienced shoulder pain and disability. Swimmers less than 12 years of age primarily had pain, whereas participants more than 12 years of age experienced pain, dissatisfaction, and disability with the use of their shoulders. The high school swimmers were the most symptomatic. Factors related to shoulder pain, dissatisfaction, and disability with shoulder use in 2 or more age groups were greater swimming exposure, a history of traumatic shoulder injury, participant-rated feeling of instability, and reduced participation in another sport or activity (cross-training). Additional factors associated with symptoms in only a single age group were less shoulder flexion ROM, less strength of shoulder internal rotation and the middle trapezius, shorter pectoralis minor, latissimus dorsi tightness, more participation in water polo, bilateral breathing, and less core endurance.

We found significant differences between participants with and without shoulder pain, disability, and dissatisfaction in exposure and physical characteristics but found no differences in age, height, mass, or body mass index. For all age groups, the +PDD group had greater exposure than the –PDD group in terms of years swum and of hours per week and hours per year practiced; however, we found differences in exposure only in the high school and masters groups. High school swimmers in the +PDD group had 1.50±1.14 years more swimming exposure than those in the –PDD group. In a study of elite competitive swimmers aged 13 to 25 years, Sein et al[3] found a correlation between years of training and supraspinatus tendon thickness on magnetic resonance imaging. They reported that all swimmers with tendon thickening had supraspinatus tendinopathy and shoulder impingement pain. In our study, both +PDD and –PDD swimmers averaged more than 15 hours per week of swimming, and some swimmers reported swimming 10000 m or more daily. Sein et al[3] also found that athletes who swam more than 15 hours per week were twice as likely to have tendinopathy as those who trained less. This might help explain our finding that high school athletes had the highest levels of pain and disability. Allegrucci et al[2] estimated that competitive swimmers performing 10 stroke cycles per 25 m and covering 10000 m per day would incur 4000 shoulder revolutions daily. Given that repetitive upper extremity usage at or above shoulder level has been identified as a risk factor for shoulder pain, it is not surprising that those with greater exposure have pain and disability.[20] In addition, the high school +PDD group had greater participation in water polo. This sport requires end-range shoulder abduction and external rotation positioning during the late cocking phase, which has been reported to result in pain due to posterosuperior impingement of the rotator cuff.[21] With posterosuperior impingement, contact occurs between the posterior glenoid rim and the insertion of the supraspinatus and the superior portion of the infraspinatus insertion into the posterior greater tuberosity. Taken collectively, our findings clearly support the association between repetitive exposure to overhead upper extremity activity and shoulder pain.

In the masters group, the +PDD group swam a greater number of hours per year (223.60±81.81 hours) than the –PDD group (163.88±81.22 hours), and a trend was seen for hours swum per week. The association between exposure and pain and disability in our study is consistent with that reported in other studies, in which the presence of supraspinatus tendinopathy in elite swimmers was predicted 85% of the time from hours swum per week alone or in combination with distance swum per week.[3] Although pitch-count rules exist for youth baseball pitchers, no exposure recommendations are available to guide coaches of youth competitive swimmers.

Whereas increased swimming exposure and participation in water polo were positively associated with pain and disability, other findings had a negative association. Specifically, the 8- to 11-year-old –PDD swimmers more frequently participated in another sport, with soccer specifically reported, and the –PDD masters swimmers more frequently participated in a walking or running program than their symptomatic counterparts. Independent *t* tests revealed no difference in the amount of time spent swimming in terms of hours per week, hours per year, or years of participation between the groups that did and did not participate in these activities. Although we cannot conclude

Table 4. Comparison of Physical Examination Measures Between Swimmers With (Positive Case) and Without (Negative Case) Shoulder Pain, Dissatisfaction, and Disability[a–c]

	Age Group											
	8–11 y			12–14 y			15–19 y			Masters		
Measure	Negative Case	Positive Case	*P*	Negative Case	Positive Case	*P*	Negative Case	Positive Case	*P*	Negative Case	Positive Case	*P*
Shoulder passive range of motion, ° (mean ± SD)												
Flexion	192.85 ± 8.52	185.11 ± 9.85	.02	188.83 ± 7.88	189.50 ± 7.91	.83	189.82 ± 8.23	187.26 ± 8.29	.24	186.35 ± 9.99	188.77 ± 9.68	.43
Flexion–triceps length	180.12 ± 11.45	173.33 ± 6.84	.10	176.80 ± 7.93	177.75 ± 6.36	.75	178.31 ± 8.76	179.89 ± 9.07	.49	174.72 ± 10.70	177.54 ± 8.15	.38
Flexion–latissimus length	183.33 ± 9.77	174.33 ± 13.77	.03	178.71 ± 10.41	182.63 ± 6.41	.32	178.57 ± 10.82	177.53 ± 11.85	.72	173.85 ± 11.69	174.08 ± 13.07	.95
External rotation	111.85 ± 12.72	112.11 ± 11.46	.96	104.09 ± 9.50	102.25 ± 12.82	.65	95.86 ± 11.26	98.63 ± 13.16	.37	92.35 ± 13.09	96.69 ± 10.94	.27
Internal rotation	41.76 ± 13.58	32.56 ± 6.02	.05	40.11 ± 13.59	39.75 ± 6.92	.94	35.78 ± 10.91	34.58 ± 6.60	.65	34.39 ± 7.87	32.54 ± 11.76	.50
Strength: manual muscle test (reduced/total[d])												
Lower trapezius	27/33 (81.8%)	9/9 (100.0%)	.31	29/35 (82.9%)	7/8 (87.5%)	>.99	56/65 (86.2%)	15/19 (78.9%)	.48	41/54 (75.9%)	11/13 (84.6%)	.72
Middle trapezius	16/33 (48.5%)	8/9 (88.9%)	.05	23/35 (65.7%)	7/8 (87.5%)	.40	47/65 (72.3%)	15/19 (78.9%)	.77	37/54 (68.5%)	10/13 (76.9%)	.74
Serratus anterior	7/33 (21.2%)	3/9 (33.3%)	.66	7/35 (20%)	2/8 (25%)	>.99	12/65 (18.5%)	1/19 (5.3%)	.28	2/54 (3.7%)	1/13 (7.7%)	.48
Strength: normalized muscle torque, Nm (mean ± SD)												
Elevation	0.05 ± 0.02	0.05 ± 0.01	.25	0.05 ± 0.02	0.06 ± 0.01	.12	0.05 ± 0.02	0.06 ± 0.01	.10	0.03 ± 0.01	0.03 ± 0.01	.44
External rotation	0.04 ± 0.01	0.04 ± 0.01	.43	0.04 ± 0.01	0.04 ± 0.01	.41	0.04 ± 0.01	0.04 ± 0.01	.36	0.02 ± 0.01	0.02 ± 0.01	.62
Internal rotation	0.04 ± 0.01	0.04 ± 0.01	.41	0.05 ± 0.01	0.04 ± 0.01	.05	0.05 ± 0.01	0.05 ± 0.01	.76	0.02 ± 0.01	0.02 ± 0.01	.55
Horizontal abduction	0.03 ± 0.01	0.04 ± 0.01	.54	0.04 ± 0.01	0.04 ± 0.01	.48	0.04 ± 0.01	0.04 ± 0.01	.83	0.02 ± 0.01	0.02 ± 0.01	.59
Normalized pectoralis minor length, cm (mean ± SD)												
Rest	0.87 ± 0.16	0.79 ± 0.12	.09	0.84 ± 0.15	0.82 ± 0.16	.61	0.83 ± 0.09	0.73 ± 0.19	.00	0.75 ± 0.29	0.78 ± 0.35	.78
Stretch	1.15 ± 0.12	1.15 ± 0.12	.95	1.12 ± 0.12	1.10 ± 0.12	.77	1.09 ± 0.08	1.00 ± 0.26	.15	0.97 ± 0.36	0.99 ± 0.45	.89
Scapular dyskinesis (obvious dyskinesis/total)	21/33 (63.6%)	7/9 (77.8%)	.69	20/35 (57.1%)	4/8 (50%)	>.99	21/65 (32.3%)	6/19 (31.6%)	.95	25/54 (46.3%)	7/13 (53.8%)	.63
Core endurance, s (mean ± SD)												
Side bridge	14.61 ± 11.43	13.51 ± 11.34	.80	24.62 ± 16.61	16.13 ± 6.17	.02	35.60 ± 18.33	28.41 ± 17.78	.13	40.78 ± 21.84	30.10 ± 14.12	.10
Prone bridge	19.13 ± 14.62	17.15 ± 20.79	.75	33.09 ± 21.47	23.94 ± 9.97	.08	54.78 ± 25.85	42.71 ± 27.96	.08	52.21 ± 24.36	55.16 ± 19.53	.69
Closed kinetic chain stability test (no. hits/15 s)	17.73 ± 3.31	19.11 ± 5.23	.34	17.40 ± 2.63	15.50 ± 6.97	.47	17.20 ± 4.41	17.90 ± 17.90	.54	15.45 ± 5.23	16.38 ± 3.50	.55

[a] Indicates that the *t* tests were performed for analysis of variables of passive range of motion, strength using normalized muscle torque, normalized pectoralis minor length, and core endurance, and the values are presented in Appendix 2.
[b] Indicates that Fisher exact probability tests were performed for analyses of variables of manual muscle test for all muscles and scapular dyskinesis (groups 8–11 years and 12–14 years of age).
[c] Indicates that χ^2 tests were performed for analyses of variables of scapular dyskinesis (groups 15–19 years of age and masters), and the values are presented in Appendix 2.
[d] *Reduced strength* was defined as movement of the scapula during application of pressure.

that participation in other activities offers a direct protective mechanism, these findings lend support to the concept of cross-training. Investigators of the effects of cross-training have concluded that adolescents participating in several sport and exercise activities throughout the year were less likely to experience neck, shoulder, or low back pain.[22] Cross-training might add to the overall fitness level and improve trunk muscle endurance and strength that aids in preventing injury.[22] In our study, soccer and walking or running might provide a mechanism for conditioning while affording relative rest for the shoulders, but specific mechanisms of cross-training to reduce symptoms merit further investigation.

Whereas Richardson and colleagues[23] found that unilateral breathing patterns increased the risk of shoulder problems, we found that the 8- to 11-year-old +PDD group had a greater incidence of a bilateral breathing pattern. Young swimmers may lack appropriate stroke mechanics, but this cannot be determined from our study. Although a trend existed for the +PDD group to breathe unilaterally at the high school level, we found no differences in breathing patterns among the other 3 age groups.

A history of a traumatic injury to the shoulder, such as a dislocation, fracture, or fall, was reported more frequently in the +PDD group in swimmers from 3 groups (age 12 years through masters). These injuries may have left residual deficits that predisposed them to pain and disability. Similarly, +PDD swimmers in the 12- to 14-year-old and high school groups more frequently answered "yes" when asked, "Does your shoulder feel unstable, or do you feel like it ever 'slips' out of place?" These findings suggest that swimmers with previous injuries or instability should be assessed to determine whether they have deficiencies that could be addressed to reduce the risk of shoulder pain.

Although paddle use has been associated with pain,[23] our data did not show differences in swim paddle use between +PDD and –PDD groups. Paddle design has changed from solid and rectangular to a shape that conforms to the hand and is perforated to reduce resistance. In addition, coaches might be more judicious in their use of paddles because of findings reported in previous studies. Individual stroke preference was not found to differ between +PDDs and –PDDs. This finding is consistent with that of Sein et al,[3] who reported that strokes have little effect on predisposition to shoulder pain. This is not surprising because practice sessions typically involve 80% freestyle swimming.[7]

Core endurance measured by time held for the side bridge position was less (8.5 seconds) in the 12- to 14-year-old +PDD group. Trends of reduced core endurance were seen for the high school and masters-level swimmers. The side and prone bridge positions evoke increased activity in the external oblique abdominis and the rectus abdominis in addition to requiring glenohumeral and scapular control. Scapular winging due to trapezius or serratus anterior fatigue would result in test termination due to loss of core position. High levels of serratus anterior muscle activity have been demonstrated for the forearm push-up plus,[24] which is essentially an isometric hold of the prone bridge exercise. Fatigue of the shoulder and trunk musculature might initiate the development of pain in the swimmer's shoulder,[25] and improved strength and endurance of the trunk muscles might protect against shoulder pain in adolescents participating in sports.[22] Our findings are in agreement with those of Beach et al,[7] who found a negative correlation between pain in competitive swimmers and isokinetic shoulder muscle endurance. Swimming has been described as an endurance-based sport,[2] so the finding of reduced endurance in symptomatic swimmers has face validity. However, a prospective longitudinal study is needed to determine whether reduced endurance predisposes swimmers to pain or injury. No swimmer terminated our testing protocol because of pain.

Reduced resting length of the pectoralis minor was found in the high school +PDD group, and a trend was seen in the youngest swimmers. People with shorter pectoralis minor muscles have displayed altered scapular kinematics, with less scapular posterior tilting and greater internal rotation during humeral elevation.[26] This might narrow the subacromial space and subsequently cause impingement of the rotator cuff. Subacromial space narrowing is greatest at 60° to 120° of humeral flexion and abduction with internal rotation,[27] which is a motion that swimmers perform thousands of times during practice. If the subacromial tissues become encroached, then injury due to compression might occur.

Reduced posterior shoulder flexibility assessed with internal rotation PROM at 90° of abduction was found in the 8- to 11-year-old +PDD swimmers. Harryman et al[28] noted that selective tightening of the posterior capsule produced superior and anterior humeral head translation. This could reduce subacromial space during overhead upper extremity use and cause shoulder pain due to impingement. Three-dimensional videography has supported this finding by showing that people with limited shoulder internal rotation were likely to experience a large amount of mechanical impingement during the swimming stroke.[29]

The 8- to 11-year-old swimmers with pain also had reduced flexion ROM with latissimus dorsi tightness. Reduced flexion ROM, which we tested with the shoulder in neutral rotation, might be attributed to capsular tightness, but reduced flexion with the pelvis posteriorly tilted and shoulder externally rotated is proposed to be due to tightness of the latissimus dorsi. If one chose to implement a stretching program to address limitations in shoulder elevation, a differentiation should be made about the restricted structure so that specific stretching exercises could be given. Theoretically, swimmers with reduced flexion ROM could have a reduced stroke length and, therefore, need additional strokes compared with swimmers with greater mobility, incurring greater shoulder load. However, because older swimmers exhibit shoulder hypermobility[7] and stretching has been reported to aggravate shoulder symptoms,[1] careful consideration should be given when evaluating potential merits of shoulder elevation stretching. Consistent with findings reported in previous studies,[6,7] none of the other age groups showed a difference in flexion ROM between swimmers with and without PDD.

The frequency of obvious scapular dyskinesis was not different between the +PDD and –PDD groups in any age group. This differs from findings reported by Bak and Magnusson[6] of "a severe lack of coordination of the scapulohumeral joint" in 33% of the symptomatic compared with 9% of the asymptomatic shoulders of 12- to 23-year-old competitive swimmers during observation of repeated arm abduction. We used a validated and reliable classification system of scapular motion assessed with swimmers holding weights while elevating in the frontal and sagittal planes, whereas Bak and Magnusson[6] used a nonvalidated system. Scapular dyskinesis was observed at all age levels and often occurred bilaterally, but this study does not support dyskinesis as being more common in swimmers with pain and disability.

Normalized internal rotation torque was less in the 12- to 14-year-old +PDD group. Electromyographic analysis of freestyle swimming has shown that the subscapularis exhibits constant muscle activity throughout the stroke in addition to its functioning for upper extremity entry and exit, so internal rotation deficits might adversely affect stroke mechanics.[30] Our finding of reduced internal rotation torque is consistent with the work of previous researchers, who reported that concentric and eccentric internal rotation strength were less in injured than uninjured competitive swimmers.[6] We also found that middle trapezius weakness was present more often in the 8- to 11-year-old +PDD group. Weak scapular stabilizing muscles might cause a loss of proximal stability that would increase demands on the rotator cuff and perhaps contribute to faulty stroke mechanics,[31] leading to shoulder pain. Strengthening of the middle trapezius and internal rotators probably should be a component of a swimmer's program to prevent shoulder injury.

Our convenience sample from 1 geographic area might not be representative of the US swimming population. However, 4 or 5 teams for each age group participated. In addition, our study lacked collegiate representation because all invited National Collegiate Athletic Association Division I teams declined participation because of their schedules. It was not practical to perform stroke biomechanical analysis on individual swimmers, although stroke mechanics might affect shoulder impingement. We investigated factors associated with shoulder pain, dissatisfaction, and disability; therefore, a cause-and-effect relationship cannot be assumed.

CONCLUSIONS

Competitive swimmers less than age 12 years experienced substantial shoulder pain, whereas older swimmers experienced pain, dissatisfaction, and disability. As a group, high school swimmers were the most symptomatic, and they incurred the greatest shoulder load, practicing an average of 16 hours per week and 600 hours or more per year. Shoulder pain, dissatisfaction, and disability were correlated positively with increased repetitive upper extremity usage in terms of swimming or water polo exposure and were correlated negatively with participation in another sport, specifically soccer for the young and running or walking for mature swimmers. Reduced shoulder flexibility and latissimus dorsi tightness were found in symptomatic young swimmers, whereas pectoralis minor tightness and decreased core endurance were associated with symptoms in swimmers aged 12 years and more. Furthermore, weakness of the middle trapezius and shoulder internal rotators was seen in the younger swimmers. Given our findings of symptom occurrence throughout the swimmer's life, a symptom-prevention program appears warranted. Our study provides a basis for other researchers to investigate the effectiveness of exposure reduction, pectoral and posterior shoulder stretching, strengthening, core endurance, and cross-training in limiting or preventing shoulder injury that might lead to pain and disability in competitive swimmers.

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REFERENCES

1. McMaster WC, Troup J. A survey of interfering shoulder pain in United States competitive swimmers. *Am J Sports Med*. 1993;21(1):67–70.
2. Allegrucci M, Whitney SL, Irrgang JJ. Clinical implications of secondary impingement of the shoulder in freestyle swimmers. *J Orthop Sports Phys Ther*. 1994;20(6):307–318.
3. Sein ML, Walton J, Linklater J, et al. Shoulder pain in elite swimmers: primarily due to swim-volume–induced supraspinatus tendinopathy. *Br J Sports Med*. 2010;44(2):105–113.
4. Pollard H, Croker D. Shoulder pain in elite swimmers. *Australas Chiropr Osteopathy*. 1999;8(3):91–95.
5. Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clin Biomech (Bristol, Avon)*. 2003;18(5):369–379.
6. Bak K, Magnusson P. Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *Am J Sports Med*. 1997;25(4):454–459.
7. Beach ML, Whitney SL, Dickoff-Hoffman S. Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. *J Orthop Sports Phys Ther*. 1992;16(6):262–268.
8. Leggin BG, Michener LA, Shaffer MA, Brenneman SK, Iannotti JP, Williams GR Jr. The Penn Shoulder Score: reliability and validity. *J Orthop Sports Phys Ther*. 2006;36(3):138–151.
9. Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand) [corrected]. The Upper Extremity Collaborative Group (UECG). *Am J Ind Med*. 1996;29(6):602–608.
10. Kendall FP, McCreary EK, Provance PG. *Muscles: Testing and Function with Posture and Pain*. 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 1993.
11. Falkel JE, Murphy TC, Murray TF. Prone positioning for testing shoulder internal and external rotation on the Cybex II® isokinetic dynamometer. *J Orthop Sports Phys Ther*. 1987;8(7):368–370.
12. McClure P, Tate AR, Kareha S, Irwin D, Zlupko E. A clinical method for identifying scapular dyskinesis, part 1: reliability. *J Athl Train*. 2009;44(2):160–164.
13. Tate AR, McClure P, Kareha S, Irwin D, Barbe MF. A clinical method for identifying scapular dyskinesis, part 2: validity. *J Athl Train*. 2009;44(2):165–173.
14. Tate AR, McClure P, Mayer D, Smith J, Gerwer A, Andrew S. Identification of risk factors for shoulder pain in female high school competitive swimmers [abstract]. *J Orthop Sports Phys Ther*. 2009;39(1):A113.
15. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil*. 1999;80(8):941–944.
16. Schellenberg KL, Lang JM, Chan KM, Burnham RS. A clinical tool for office assessment of lumbar spine stabilization endurance: prone and supine bridge maneuvers. *Am J Phys Med Rehabil*. 2007;86(5):380–386.
17. Goldbeck TG, Davies GJ. Test-retest reliability of the Closed Kinetic Chain Upper Extremity Stability Test: a clinical field test. *J Sport Rehabil*. 2000;9(1):35–45.
18. Borstad JD. Measurement of pectoralis minor muscle length: validation and clinical application. *J Orthop Sports Phys Ther*. 2008;38(4):169–174.
19. Borstad JD, Ludewig PM. Comparison of three stretches for the pectoralis minor muscle. *J Shoulder Elbow Surg*. 2006;15(3):324–330.
20. Silverstein BA, Bao SS, Fan ZJ, et al. Rotator cuff syndrome: personal, work-related psychosocial and physical load factors. *J Occup Environ Med*. 2008;50(9):1062–1076.
21. Webster MJ, Morris ME, Galna B. Shoulder pain in water polo: a systematic review of the literature. *J Sci Med Sport*. 2009;12(1):3–11.
22. Auvinen JP, Tammelin TH, Taimela SP, Zitting PJ, Mutanen PO, Karppinen JI. Musculoskeletal pains in relation to different sport and exercise activities in youth. *Med Sci Sports Exerc*. 2008;40(11):1890–1900.
23. Richardson AB, Jobe FW, Collins HR. The shoulder in competitive swimming. *Am J Sports Med*. 1980;8(3):159–163.
24. Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. *Am J Sports Med*. 2004;32(2):484–493.
25. Stocker D, Pink M, Jobe FW. Comparison of shoulder injury in collegiate- and master's-level swimmers. *Clin J Sport Med*. 1995;5(1):4–8.
26. Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. *J Orthop Sports Phys Ther*. 2005;35(4):227–238.
27. Brossmann J, Preidler KW, Pedowitz RA, White LM, Trudell D, Resnick D. Shoulder impingement syndrome: influence of shoulder position on rotator cuff impingement: an anatomic study. *AJR Am J Roentgenol*. 1996;167(6):1511–1515.
28. Harryman DT II, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA III. Translation of the humeral head on the glenoid with passive glenohumeral motion. *J Bone Joint Surg Am*. 1990;72(9):1334–1343.
29. Yanai T, Hay JG. Shoulder impingement in front-crawl swimming, II: analysis of stroking technique. *Med Sci Sports Exerc*. 2000;32(1):30–40.
30. Pink M, Perry J, Browne A, Scovazzo ML, Kerrigan J. The normal shoulder during freestyle swimming: an electromyographic and cinematographic analysis of twelve muscles. *Am J Sports Med*. 1991;19(6):569–576.
31. Russ DW. In-season management of shoulder pain in a collegiate swimmer: a team approach. *J Orthop Sports Phys Ther*. 1998;27(5):371–376.

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Appendix 1. The *t* Values Associated With Quantification of Swimming Exposure

	Age Group							
	8–11 y		12–14 y		15–19 y		Masters	
Swimming Exposure	*t*	Degrees of Freedom	*t*	Degrees of Freedom	*t*	Degrees of Freedom	*t*	Degrees of Freedom
Time swum, y	−0.33	40	1.07	40	2.73	48.68	1.54	65
Time swum per week, h	1.36	40	0.59	39	0.37	82	1.92	65
Time swum per year, h	0.64	9.69	0.41	41	0.53	82	2.38	65

Appendix 2. The *t* Values and χ^2 Values[a] Associated With Comparison of Physical Examination Measures Between Swimmers With and Without Shoulder Pain, Dissatisfaction, and Disability

	Age Group									
	8–11 y		12–14 y		15–19 y			Masters		
Measure	*t*	Degrees of Freedom	*t*	Degrees of Freedom	*t*	Degrees of Freedom	χ^2_1	*t*	Degrees of Freedom	χ^2_1
Shoulder passive range of motion, °										
Flexion	−2.34	40	0.22	41	−1.19	82	NA	0.79	65	NA
Flexion–triceps length	−1.69	40	0.32	41	0.69	82	NA	0.89	65	NA
Flexion–latissimus length	−2.24	40	1.01	41	−0.36	82	NA	0.06	65	NA
External rotation	0.06	40	−0.46	41	0.91	82	NA	1.11	65	NA
Internal rotation	−1.97	40	−0.07	41	−0.46	82	NA	−0.69	65	NA
Strength: manual muscle test (reduced/total[a])										
Lower trapezius	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Middle trapezius	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Serratus anterior	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Strength: normalized muscle torque, Nm										
Elevation	1.17	40	1.58	41	1.65	82	NA	−0.78	65	NA
External rotation	0.80	40	−0.83	41	0.92	82	NA	−0.50	65	NA
Internal rotation	0.83	40	−1.98	41	−0.31	82	NA	−0.61	65	NA
Horizontal abduction	0.62	40	0.72	41	0.21	82	NA	−0.54	65	NA
Normalized pectoralis minor length, cm										
Rest	−1.8	17.3	−0.51	41	−3.37	82	NA	0.28	65	NA
Stretch	−0.12	40	−0.29	41	−1.5	19.05	NA	0.14	65	NA
Scapular dyskinesis (obvious dyskinesis/total)[b]	NA	NA	NA	NA	NA	NA	0.004	NA	NA	0.24
Core endurance, s										
Side bridge	−0.26	40	−2.39	31.55	−1.51	82	NA	−1.68	65	NA
Prone bridge	−0.33	40	−1.81	24.11	−1.76	82	NA	0.41	65	NA
Closed kinetic chain stability test (no. hits/15 s)	0.96	40	−0.76	7.5	0.61	82	NA	0.61	64	NA

Abbreviation: NA, not applicable.

[a] *Reduced strength* was defined as movement of the scapula during application of pressure.

[b] Indicates that χ^2 tests were performed for analyses of variables of scapular dyskinesis for groups 15–19 years of age and masters.