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Prediction of Shoulder Pain in Youth Competitive Swimmers

The Development and Internal Validation of a Prognostic Prediction Model

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Background: Knowledge of predictors for shoulder pain in swimmers can assist professionals working with the athlete in developing optimal prevention strategies. However, study methodology and limited available data have constrained a comprehensive understanding of which factors cause shoulder pain.

Purpose: To investigate risk factors and develop and internally validate a multivariable prognostic model for the prediction of shoulder pain in swimmers.

Study Design: Cohort study; Level of evidence, 2.

Methods: A total of 201 pain-free club- to international-level competitive swimmers were followed for 2 consecutive seasons. The cohort consisted of 96 male (mean ± SD age, 13.9 ± 2.2 years) and 105 female (13.9 ± 2.2 years) swimmers. Demographic, sport-specific, and musculoskeletal characteristics were assessed every 6 months. Swim-training exposure was observed prospectively. Shoulder pain interfering with training was the primary outcome. Multiple imputation was used to cope with missing data. The final model was estimated using multivariable logistic regression. We applied bootstrapping to internally validate the model and correct for overoptimism.

Results: A total of 42 new cases of shoulder pain were recorded during the study. Average duration of follow-up was 1.1 years. Predictors included in the final model were acute:chronic workload ratio (odds ratio [OR], 4.31; 95% CI, 1.00-18.54), competitive level (OR, 0.19; 95% CI, 0.06-0.63), shoulder flexion range of motion, posterior shoulder muscle endurance (OR, 0.96; 95% CI, 0.92-0.99), and hand entry position error (OR, 0.37; 95% CI, 0.16-0.91). After internal validation, this model maintained good calibration and discriminative power (area under the receiver operating characteristic curve, 0.71; 95% CI, 0.60-0.94).

Conclusion: Our model consists of parameters that are readily measurable in a swimming setting, allowing the identification of swimmers at risk for shoulder pain. Multivariable logistic regression showed the strongest predictors for shoulder pain were regional competitive swimming level, acute:chronic workload ratio, posterior shoulder muscle endurance, and hand entry error.

Keywords: swimming; risk factors; injury prevention; shoulder

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Shoulder pain is widely prevalent across all levels of competitive swimming and can be devastating and potentially career ending for many athletes.[9,12] Elite competitive swimmers can swim up to 18,000 m each day,[29] and they often practice 5 to 7 days per week and sometimes twice daily. Eighty percent of this practice consists of the freestyle stroke,[52] resulting in an enormous amount of repetitive shoulder revolutions each day. In contrast to most other sports, where the legs initiate and provide a substantial contribution to the propulsive force, swimming athletes primarily use the upper body.[39] This heavy load in combination with an inherently unstable shoulder places tremendous stress on joint and periarticular tissue, making it prone to various injuries.

Research has identified a variety of characteristics that may contribute to shoulder pain including lack of scapular stability, muscle strength imbalances, changes in mobility, swimming volume, poor stroke mechanics, competitive level, and history of injury.[18,46] However, study methodology and limited available data have constrained a comprehensive understanding to the extent that these associated factors are the cause or effect of the swimmer's shoulder pain. In a prospective study, high and low shoulder

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external rotation range of motion (ROM) was significantly associated with shoulder pain.[53] However, no information was given on the performance or validation of the model that was used. Moreover, a study conducting, developing, and validating a clinical prediction model for shoulder pain in swimmers is lacking.

Knowledge of risk factors that predict shoulder pain can assist professionals working with swimmers in developing prevention strategies. Consequently, the aim of the current study was to identify predictors and develop and validate a multivariable prognostic model for the prediction of shoulder pain in competitive swimmers.

METHODS

A prospective study was conducted from January 2017 through September 2019. We used the TRIPOD guidelines (Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis).[31] Two hundred competitive swimmers were needed to achieve a power of 80%. We assumed a 50% baseline probability of shoulder pain (odds of 1) based on previously reported prevalence rates of 40% to 91% and an incidence rate of 4 injuries per 1000 hours of training.[2,41] Loss to follow-up was addressed using censoring.[35] We defined shoulder pain as a time-loss injury, recording an incident as soon as the athlete missed part of a single training or competition session owing to clear pain in the shoulder region, even if he or she returned for the next session.[33,48]

Participants

Swimmers between the ages of 10 and 40 years and active in competitive swimming clubs were recruited for this study. Inclusion criteria were an average minimum of 4 hours of swimming per week, excluding competition, and the intention to participate for at least 12 months. Exclusion criteria were shoulder pain at the start of the study and 1 month before onset of the study or major shoulder trauma or surgery within 12 months before onset of the study. Swimmers who had any neurologic, systemic, metabolic, rheumatologic, or cardiovascular disease were excluded from the study. All participants read and signed an informed consent form approved by the committee for medical ethics of the university hospital UZA (UZA-UAntwerp; B300201630081).

Procedure

Swimmers were tested at baseline and again after 6, 12, 18, and 24 months. All participants were assessed at poolside after a 10-minute standardized warm-up on the VASA swim ergometer (4 × 2 minutes + 30-second rest). First, participants' demographic and sport-specific characteristics were registered. The swimmers' competitive level was determined per their qualification in international, national, regional, or club events during the previous season. Furthermore, the 36-Item Short Form Health Survey (SF-36) and the Disabilities of the Arm, Shoulder and Hand (DASH) were used to obtain the swimmers' functional status and shoulder function in daily life and during swimming.[19,27]

Next, scapular dyskinesis, thoracic rotation, shoulder ROM, pectoralis minor length, shoulder internal and external rotation strength, posterior shoulder muscle endurance (PSE), core endurance, and pain threshold were assessed in a fixed order. At the end of the test session, we captured the swimmers' freestyle stroke pattern. Swimming volume was prospectively recorded as the distance swum per week. We calculated the acute:chronic workload ratio (ACWR) of swim training by dividing the distance swum in the previous week by the distance that had been swum as a rolling average over the past 4 weeks, incorporating the previous week.[6]

The following positions were visually assessed for scapular dyskinesis: both arms relaxed next to the body (thumbs facing forward), hands placed on the iliac crest (thumbs facing backward), both arms abducted to 90° in the frontal plane (thumbs facing up), active lateral shoulder abduction of 0° to 180°, and active shoulder elevation of 0° to 90°.[44] Each condition was scored separately on a yes/no scale for the presence of tilting or winging. Clinical observation of the scapula has been suggested to have moderate to substantial reliability in static (k = 0.48) and dynamic (k = 0.78) conditions, respectively.[45]

Thoracic rotation and shoulder ROM were measured bilaterally using a fluid-filled bubble gravity–based inclinometer (Plurimeter; Dr Rippstein). Thoracic rotation was measured in degrees using the lumbar-locked rotation test as adapted from previous research.[21] We instructed the participants to sit back on the heels in a 4-point kneeling position and grasp the neck. Next, the examiner (S.F.) placed the inclinometer on the spine at level T1-T2 and measured thoracic rotation while the participants slowly rotated ipsilaterally. Shoulder ROM was assessed in the following order: prone active external and internal rotation at 90° of abduction; supine active shoulder flexion in neutral rotation; and supine passive shoulder flexion with the humerus externally rotated, knees and hips flexed, and abdominal muscles actively contracted for latissimus dorsi flexibility.[23] Intrarater reliability of the lumbar-locked rotation test was established a priori (intraclass correlation [ICC], 0.91-0.96).[11] Intrarater reliability for

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shoulder ROM was good to excellent (ICC, 0.82-0.99).[13] We used the average of 3 consecutive trials per measurement for analysis.

Pectoralis minor muscle length was assessed using a Vernier Caliper (0-300 mm; Hogetex) according to the protocol of Borstad.[8] First, swimmers were positioned supine and instructed to exhale to reduce variations in muscle length resulting from respiration. Next, the examiner measured the distance between the inferomedial aspect of the coracoid process and the caudal edge of the fourth rib at the sternum. The average of 2 measurements was used for analysis. Normalized pectoralis minor length was obtained by dividing the pectoral length by each participant's height and multiplying by 100. Good to excellent intrarater reliability has been established for the pectoralis minor length measurement (ICC, 0.76-0.93).[43]

PSE was tested bilaterally by counting the number of repetitions performed during the posterior shoulder endurance test.[32] The swimmers were in the prone position and held the test arm off the table and perpendicular to the floor. We then instructed the swimmers to elevate the arm up to 90° of horizontal abduction, maintain this position for 1 second, and then slowly release. This was performed until the swimmers were unable to hold the arm in the abducted position, compensated with elevation or rotation of the entire upper torso, or verbally reported the inability to continue. Participants held a dumbbell with a body weight–dependent load (<36.29 kg, 0.50 kg; 36.29-68.04 kg, 1 kg; and >68.04 kg, 2 kg). The PSE has shown good test-retest reliability (ICC, 0.85).[32]

Bilateral shoulder peak muscle force was assessed in kilograms using a handheld dynamometer (microFET; Hoggan Industries) in the following order: shoulder internal and external rotation in the prone position and the shoulder abducted to 90° and shoulder elevation in the empty-can position (90° of shoulder elevation in the scapular plane and internal rotation). We instructed the participants to maintain the beginning position of the arm while the examiner applied a gradually increasing force on the distal forearm. Thirty seconds of rest occurred between trials. The average of 2 consecutive trials was used for data analysis.

Finally, the swimmers' freestyle swimming stroke was analyzed for biomechanical errors according to the procedure of Virag et al.[52] Each swimmer was instructed to swim 2 lengths of the pool at 50% to 70% of one's maximum freestyle race speed. The examiner positioned 2 cameras at the end of the swimming lane for a frontal view (1 under the water and 1 above; GoPro, Inc), as well as 1 underwater camera (GoPro, Inc) adjusted to capture the final 5 m of the lane for the lateral view. The first stroke cycle that was completely within view of all cameras was analyzed for errors in 8 biomechanical parameters: hand entry position (HE), fingers-first HE, pull-through elbow position, pull-through movement, recovery elbow position, body roll, head position, and breathing side. The main examiner (S.F.) was trained in analyzing the swimming technique by a performance analyst at the Flemish Swimming Federation. Kappa interrater reliability scores were established for the biomechanical parameters (ICC, 0.50-0.90).[52]

All clinical measurements were performed by the main examiner (S.F., master in rehabilitation sciences and physiotherapy with 2 years of clinical experience), as trained by an experienced physiotherapist (K.K., master in rehabilitation sciences and physiotherapy with >10 years of clinical experience). Swimming stroke images and growth parameters were captured by graduate physical therapy students, as trained by the main examiner. Affected swimmers were retested by means of the complete test battery within 10 days of onset of their pain. Furthermore, we assessed shoulder functioning, pain, and dissatisfaction using the DASH, Penn Shoulder Score, and Shoulder Disability Questionnaire. These questionnaires have been validated in Dutch for a variety of shoulder disorders.[24,50,51]

Data Analysis

Data were analyzed using R Version 3.6.1 (R Foundation for Statistical Computing). The most relevant predictors after univariable screening ($P < .20$) were included in a multivariable logistic regression with shoulder pain as a dichotomous outcome. Variables with P values <.15 (Wald test) were retained. Goodness of fit was assessed using the Akaike information criterion index. First, missing data in selected predictor variables were imputed using multiple imputation by chained equations ($m = 1000$).[49] We then pooled the estimated regression coefficients obtained in each of the 1000 imputed data sets using the inference methods for multiple imputation described by Little and Rubin[25] to obtain the final prognostic model. Next, the model's calibration and discriminative performance was estimated and pooled using the Rubin rules. We adjusted for overfitting by applying 250 iterations (resampling) of bootstrapping, which is called internal validation. The Akaike information criterion, adjusted odds ratios (ORs) with 95% CIs, and pseudo R^2 were extracted from the final prognostic model.

RESULTS

Participants

A total of 201 competitive swimmers were recruited (mean ± SD age, 13.9 ± 2.2 years; 96 male, 13.9 ± 2.2 years; 105 female, 13.9 ± 2.2 years). Median follow-up time was 1.1 years (SD ± 2.2). A total of 72 swimmers dropped out for reasons unrelated to the outcome (53 for other sports, 15 for recreational swimming, 4 for injuries unrelated to the shoulder). Figure 1 represents a flow diagram of follow-up at each stage of the study. Shoulder pain was observed in 42 of the 201 competitive swimmers. This corresponded with an incidence of approximately 30% after censoring for dropouts and injuries at various times during follow-up. Swimmers with shoulder pain reported a 20% disability during swim training on the DASH sports module and a 22% disability in daily life on the Shoulder Disability Questionnaire. Table 1 contains detailed characteristics of the study population.

TABLE 1
Baseline Characteristics of Swimmers With and Without Shoulder Pain[a]

	Injured (n = 42)	Uninjured (n = 159)	All (N = 201)
Time of follow-up, y[b]	1.01 (1.98)	1.14 (2.20)	1.07 (2.20)
Age, y	13.8 ± 2.3	14.0 ± 2.2	13.9 ± 2.2
Sex, male:female	18:24	78:81	96:105
Height, cm	163.1 ± 13.0	165.2 ± 12.2	164.8 ± 12.4
Weight, kg	53.28 ± 14.05	54.73 ± 12.83	54.42 ± 13.08
Arm span, cm	164.4 ± 15.3	166.4 ± 13.7	166.0 ± 14.1
Lifetime exposure, y	4.74 ± 2.33	4.37 ± 2.41	4.57 ± 2.37
Swimming volume per week			
Time, h	8.52 ± 2.99	9.14 ± 3.70	8.65 ± 3.15
Distance, m[b]	20,505.60 (30,286.70)	16,807.14 (32,000.00)	17,277.82 (32,286.70)
Competitive level			
International	6	11	17
National	19	64	83
Regional	9	70	79
Club	8	14	22

[a] Values are presented as mean ± SD or No. unless noted otherwise. Independent-samples *t* test showed no significant differences for baseline characteristics between swimmers with and without shoulder pain ($P < .05$).

[b] Median (range).

Prediction Model for the Development of Shoulder Pain in Swimmers

Competitive level, ACWR, shoulder flexion ROM, PSE, SF-36 emotional disability, and HE and recovery stroke errors appeared to be relevant predictors according to the univariate analyses. Multivariable logistic regression showed the strongest predictors for shoulder pain were regional competitive level (OR, 0.19; 95% CI, 0.06-0.63), ACWR (OR, 4.31; 95% CI, 1.00-18.54), PSE (OR, 0.96; 95% CI, 0.92-1.00), and HE error (OR, 0.37; 95% CI, 0.16-0.91). Table 2 displays the pooled coefficients and ORs from the prognostic model. The pseudo R^2 was 0.14. There were no significant interactions among the main predictors. Analysis using the original data set led to similar results.

Model Performance

Calibration refers to the agreement between the observed outcome of shoulder pain and its predicted probability based on information from the predictor variables in the model. Visual inspection showed an acceptable calibration; that is, there was no systematic deviation from the diagonal, which represents perfect calibration (Figure 2). The median Hosmer-Lemeshow goodness-of-fit test was 0.44 and may indicate no significant difference between predicted and observed outcomes.

Discrimination can be assessed using the area under the receiver operating characteristic curve (AUC), which summarizes the model's ability to distinguish between swimmers with and without shoulder pain.[14] Figure 3A shows good discrimination of the model (AUC, 0.76; 95% CI, 0.55-0.89). The predictive ability of the model is described by using its sensitivity (detect true positives), specificity (detect true negatives), positive predictive value (how many with a positive test are injured), and negative predictive value (how many with a negative test are not injured). Figure 3B shows the sensitivity and specificity

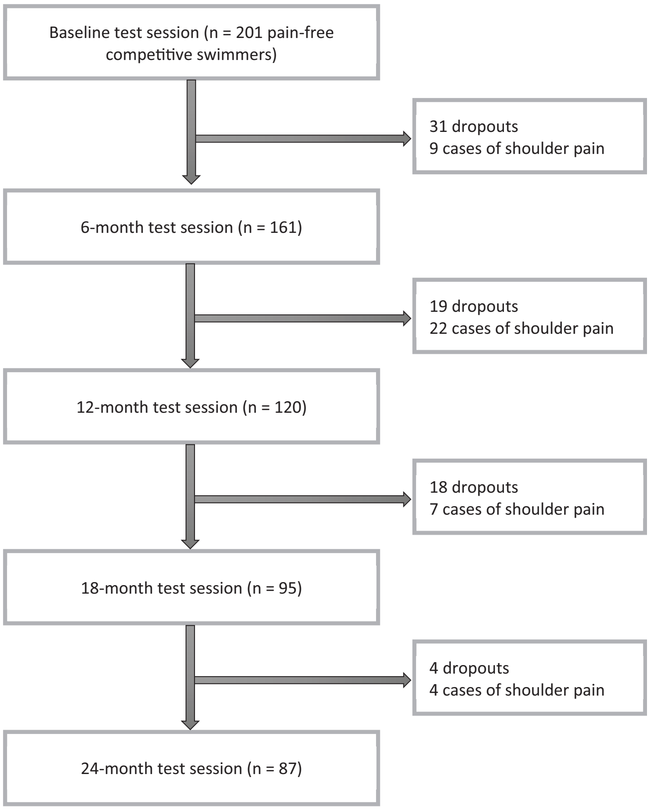

Figure 1. Flow diagram representing follow-up, dropout, and new cases of shoulder pain at each stage of the prospective study.

TABLE 2
Multivariable Logistic Regression Model After Multiple Imputation for Missing Data Containing All Retained Variables After Manual Elimination (N = 201)[a]

Final Model	β (SE)	Odds Ratio (95% CI)	*P* Value
Acute:chronic workload	1.46 (0.75)	4.31 (1.001-18.537)	**.049**
Shoulder flexion range of motion	–0.04 (0.02)	0.96 (0.918-1.004)	.078
Posterior shoulder muscle endurance	–0.04 (0.02)	0.96 (0.916-0.998)	**.041**
Hand entry position error	–0.98 (0.45)	0.37 (0.155-0.906)	**.029**
Competitive level			**.008**
Regional vs club	–1.66 (0.61)	0.19 (0.058-0.629)	**.007**
National vs club	–0.54 (0.56)	0.59 (0.195-1.754)	.339
International vs club	0.35 (0.75)	1.417 (0.327-6.146)	.641

[a] Pooled Hosmer-Lemeshow = 0.45. Pooled Akaike information criterion = 193.46. Pooled McFadden R^2 = 0.14. Bold indicates significance ($P < .05$).

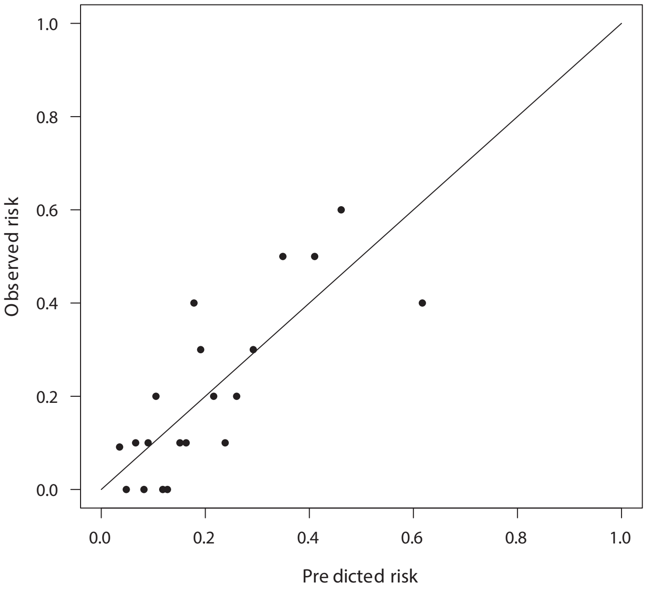

Figure 2. Calibration plot of the prognostic model for the prediction of shoulder pain. The frequencies of the observed vs predicted outcomes are plotted. Results from the first imputed data set (Hosmer-Lemeshow, 0.57).

of the model. Table 3 contains the sensitivity, specificity, and predictive values for specific cutoff points of predicted probability of shoulder pain. Original data provided a Hosmer-Lemeshow *P* value of .23. The AUC of the model was 0.78 (95% CI, 0.69-0.88).

Internal Validation

The performance of a predictive model may be overestimated when simply determined on the recruited sample. Therefore, we performed 250 iterations of bootstrapping to provide a more accurate estimate of model performance in new competitive swimmers. The optimism-corrected AUC was 0.71 (95% CI, 0.60-0.94).

DISCUSSION

Main Findings

We used prospective data to develop and internally validate a prognostic model for the prediction of shoulder pain in competitive swimmers. The present study observed a 30% incidence of shoulder pain. The model provided a rather weak pseudo R^2, which expresses that the predictors contribute little to the explanation of the response variable. However, with binary responses, such as shoulder pain, values of pseudo R^2 tend to be low even for an underlying perfect regression relationship,[15,30,34] and performance of a prediction model needs to be further quantified in terms of calibration and discrimination.[42] Our prognostic model revealed good calibration and discriminative power after internal validation (AUC, 0.71; 95% CI, 0.60-0.94), yet external validation is recommended before implementation in clinical practice.

Interpretation of Predictor Findings

The present study highlights the importance of ACWR as a predictor for shoulder pain. Analysis revealed that for swimmers who were exposed to a 1-unit increase in the ACWR, the odds for shoulder pain increased by a factor of 4.3. ACWR represented the swimmers' recent volume relative to the volume for which they had been prepared. Given the younger age of swimmers in our cohort, results of this study provide support for the view that a sudden increase in swim training volume in young adolescent swimmers may increase the risk of injury.[12] Notwithstanding these concerns, it is important to point out that the relationship between ACWR and injury has mainly been developed on the basis of team sports and that the exact ratios used for a particular purpose of training may need to be individualized in swimming. In addition, future research needs to examine the best model according to the data instead of relying on the quadratic relation as a reference model.[20] Until then, recommendations should be applied with caution.

Previous research has shown moderate evidence for competitive level as a risk factor for shoulder pain.[18]

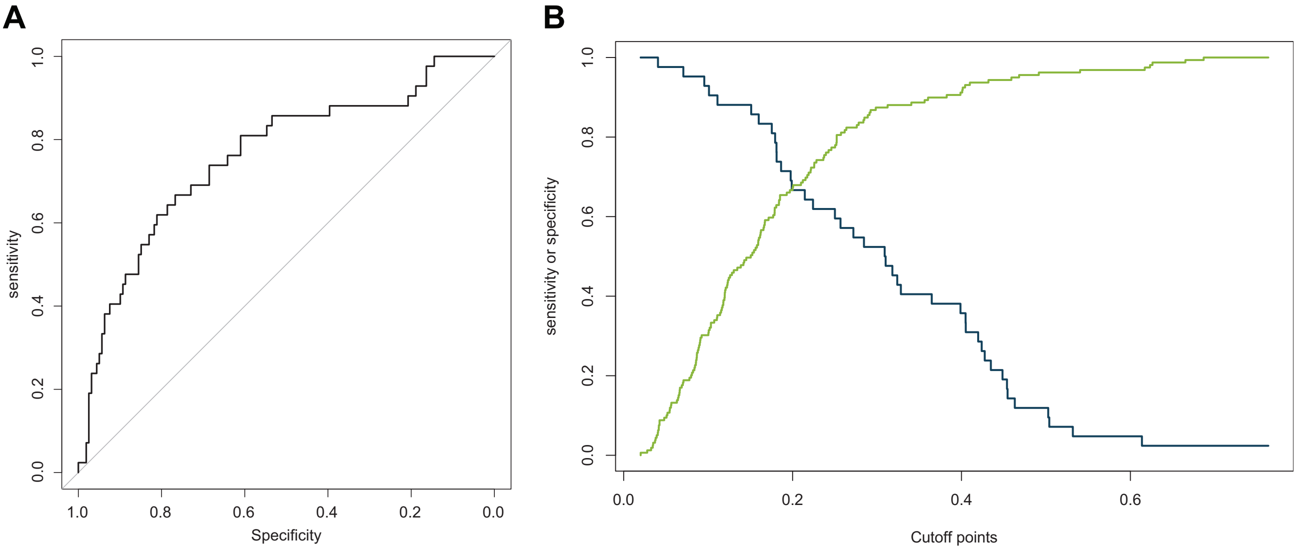

Figure 3. (A) Receiver operating characteristic curves and area under the receiver operating characteristic curve for the model plotted with the pooled predicted probabilities of shoulder pain. The area under the curve for this model, before adjustment for overfitting, was 0.76 (95% CI, 0.55-0.89). (B) Visualization of the cutoff points at which optimal sensitivity (ascending line) and specificity (descending line) were achieved.

TABLE 3
Sensitivity and Specificity of the Prognostic Model for the Prediction of Shoulder Pain in Swimmers[a]

Cutoff	No. (%)[b]	Sensitivity, %	Specificity, %	PPV, %	1 – NPV, %
>0.10	88 (44)	93	30	26	6
>0.20	134 (67)	67	67	35	12
>0.30	161 (80)	52	87	52	13
>0.50	158 (79)	12	96	45	19
>0.60	156 (78)	5	97	29	21

[a] NPV, negative predictive value; PPV, positive predictive value.
[b] Proportion correctly classified.

However, it is not clear to what extent different levels of swimming contribute to injury. Results of this study revealed that the risk of shoulder pain was lower in regional-level as compared with club-level swimming. Although increased competitive level generally comes with greater training loads, the lack of consistency in training at club-level swimming may result in less preparedness for increases in the ACWR, hence increasing the risk of injury.

Next, fatigue of the shoulder muscles is another factor that may affect the swimmer's shoulder. Freestyle swimming requires repeated activation of the posterior shoulder and scapular stabilization muscles, making these susceptible to fatigue.[38] The PSE test measures the endurance capability of these muscles based on studies that demonstrated high activation levels of the middle trapezius, lower trapezius, infraspinatus, and supraspinatus during this maneuver.[32] The present study highlights the importance of muscle endurance, as, for swimmers with a 1-count increase in PSE score, the odds for shoulder pain decreased by a factor of 0.95 (ie, decreases by 5%). Consistent with previous research, this result points to a negative association between pain and shoulder muscle endurance,[5] suggesting that training the posterior shoulder muscles for sufficient endurance is recommended to protect against injury.[10]

Biomechanical errors in the freestyle stroke have been considered potentially harmful to the shoulder.[37,39,40,52] Interestingly, results of our study revealed that the odds of shoulder pain were lower for swimmers who had an HE error. Swimmers are supposed to enter the hand in line between the head and their shoulder,[52] yet most of our athletes seemed to enter the hand more laterally. Although this stroke alteration is considered incorrect, it may be an attempt to avoid extreme positions of the shoulder during the repetitive flexion and internal rotation.[39,40,54,55] In fact, previous research has found that swimmers who experienced impingement pain in some stroke cycles tried to avoid the pain in other cycles.[54,55] Explorative analysis revealed no significant differences in HE across competitive levels of swimming nor any relationship with age. Nevertheless, we recommend that future research explore whether this is an adaptive mechanism seen in so many successful overhead athletes.

Findings of this study could not confirm a significant contribution of shoulder flexion ROM, yet research has highlighted its relevance for reducing the risk of injury.[17,47] In fact, before delivering the propulsive force, the swimmer typically strives for greatest available reach,[3,17] but this requires sufficient shoulder flexion ROM. Recent studies have revealed greater shoulder flexion ROM in pain-free competitive swimmers as compared with swimmers with injury,[5,47] suggesting that greater flexion ROM may reduce the risk of injury, as the swimmers require fewer strokes per lap, which may reduce the load on the shoulder. Given that a similar trend appears to be present in our prospective data, we recommend that future research explore the contribution of shoulder flexion ROM in the development of shoulder pain in swimmers.

Strengths and Limitations

To our knowledge, this is the first study to develop and internally validate a prediction model for shoulder pain in swimmers. A wide range of relevant multimodal predictors was investigated on the basis of previous research.[41,47,52,53] We applied multiple imputation and internal validation using bootstrapping. There was a high dropout rate over the course of the 2 years; hence, censoring was applied in our analysis. Finally, our prognostic model consists of parameters that can easily be assessed in a swimming setting. We believe that this greatly expands its clinical utility and helps to inform and facilitate counseling of swimmers at risk.

Limitations of our study need to be addressed. Most notably, the relatively young cohort of swimmers recruited may have influenced the risk of injury. In fact, skeletally immature athletes are often exposed to upper extremity injuries,[4] with a reported 45% of these injuries involving the shoulder.[26] Young swimmers develop through adolescence at various rates and times,[22] and although the body may not have fully matured, it is already being exposed to enormous volumes of swimming. Combined with the extreme stresses of repetitive motion, periods of rapid growth may have predisposed the swimmers to injury and pain[28]; hence, it is unknown how the findings translate to adult competitive-level swimmers. However, despite the given risk of injury, our cohort of swimmers swam substantially less than what has been reported in the literature to increase the risk of shoulder pain.[41] This may explain the lower incidence of shoulder pain as compared with that reported in previous research. Furthermore, we point out that sports injuries are complex and have been suggested to arise not only from predictive factors but from interactions among a "web of determinants."[36] Although we investigated many variables, it is possible that some determinants relevant in explaining the variance in our outcome have been missed. This makes further research identifying these factors warranted. Next, the experience of pain remains partly subjective and, in spite of our close-to-real-life monitoring, may be mediated by the sport's context, pain tolerance, and coping factors.[7]

Finally, the cutoff at which optimal predictive power was achieved resulted in 67% sensitivity and 67% specificity of our model. These results may seem moderate, especially when compared with performances obtained in diagnostic studies. However, it is the close temporal relationship between predictors and outcome in diagnostic studies that generally leads to higher discriminative power, while the performance of our model should be interpreted in light of the difficulty of predicting binary outcomes with near certainty.[16] In addition, the optimal cutoff value should be determined according to the clinical application of the test.[1] If, for instance, a probability >0.1 is chosen as the threshold for higher risk of shoulder pain, 93% (sensitivity) of those who would have had shoulder pain would have received preventive treatment, as their prognostic test was positive. Given the high prevalence and potentially career-ending threat of shoulder pain in swimmers, as well as the ease of implementing prevention in dry-land training sessions, we would recommend avoiding false negatives and therefore increasing the model's sensitivity.

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