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Intrinsic Risk Factors for Noncontact Musculoskeletal Injury in Collegiate Swimmers: A Prospective Cohort Study

Travis R. Pollen, PhD*; Meghan Warren, PhD, MPH, PT‡; David Ebaugh, PhD, PT§; Jennifer A. Taylor, PhD, MPH†; Sheri P. Silfies, PhD, PT||

*Department of Physical Therapy and Rehabilitation Sciences and †Department of Environmental and Occupational Health, Dornsife School of Public Health, Drexel University, Philadelphia, PA; ‡Department of Physical Therapy and Athletic Training, Northern Arizona University, Flagstaff; §Department of Physical Therapy, University of Delaware, Newark; ||Department of Exercise Science, University of South Carolina, Columbia. Dr Warren is now at Patient-Centered Outcomes Research Institute, Washington, DC.

Context: Shoulder pain is pervasive in swimmers of all ages. However, given the limited number of prospective studies, injury risk factors in swimmers remain uncertain.

Objective: To determine the extent to which the risk factors of previous injury, poor movement competency, erroneous freestyle swimming technique, and low perceived susceptibility to sport injury were associated with noncontact musculoskeletal injury in collegiate swimmers.

Design: Prospective cohort study.

Setting: College natatorium.

Patients or Other Participants: Thirty-seven National College Athletic Association Division III swimmers (21 females, 16 males; median age = 19 years [interquartile range = 3 years], height = 175 ± 10 cm; mass = 70.0 ± 10.9 kg).

Main Outcome Measure(s): Participants completed preseason questionnaires on their previous injuries and perceived susceptibility to sport injury. At the beginning of the season, they completed the Movement System Screening Tool and the Freestyle Swimming Technique Assessment. Logistic regression was used to calculate odds ratios (ORs) with 95% CIs for the association between each risk factor and injury.

Results: Eleven of the 37 participants (29.7%) sustained an injury. Univariate analyses identified 2 risk factors: previous injury (OR = 8.89 [95% CI = 1.78, 44.48]) and crossover hand positions during the freestyle entry phase (OR = 8.50 [95% CI = 1.50, 48.05]). After adjusting for previous injury, we found that a higher perceived percentage chance of injury (1 item from the Perceived Susceptibility to Sport Injury) decreased the injury odds (adjusted OR = 0.11 [95% CI = 0.02, 0.82]). Poor movement competency was not associated with injury ($P > .05$).

Conclusions: Previous injury, a crossover hand-entry position in freestyle, and a low perceived percentage chance of injury were associated with increased injury odds. Ascertaining injury histories and assessing for crossover positions may help identify swimmers with an elevated injury risk and inform injury-prevention strategies.

Key Words: athletic injuries, shoulder pain, freestyle swimming

Key Points

- Swimmers who exhibited a crossover hand position during the hand-entry phase of the freestyle stroke had 8.5 times higher odds of injury.
- After adjusting for previous injury, we observed that the odds of injury increased almost 9-fold for every 1-point decrease in the perceived percentage chance of injury.
- Poor movement competency as measured using the Movement System Screening Tool was not a risk factor for injury.

As many as 9 in 10 competitive swimmers aged 13 to 25 years report shoulder pain.[1] This high prevalence is plausible given the high training loads and repetitive stress of the sport.[1] For example, at the collegiate level, swimmers can train 6 to 7 sessions per week for a total of >23 km.[2] Given the predominant overuse mechanism of injury at the collegiate level,[3,4] many swimming injuries may be preventable. To reduce the incidence of swimming injuries, we must identify risk factors.[5] The current evidence for risk factors in swimmers lacks certainty because of a paucity of prospective studies.[6] Authors[2,7] of 2 prospective studies identified previous injury as a risk factor for future pain or injury, but authors[8] of 1 study found no relationship between previous and future shoulder pain. In several prospective investigations, researchers[7–12] found associations between various measures of shoulder strength, endurance, or range of motion (ROM) and injury across age groups.

Many potential risk factors for injury have not been examined prospectively in swimmers. For example, *poor* *movement competency* (ie, the inability to execute key sporting movements) has been identified as a risk factor across sports.[13–15] Although swimmers have participated in these multisport samples,[13–15] no researchers have assessed the relationship between movement competency and injury in swimmers alone. In addition, despite the widespread belief that poor swimming technique increases injury risk,[16–18] the authors[12] of only 1 peer-reviewed prospective study have investigated this relationship. Finally, despite the well-documented role that psychosocial factors play in injury,[19–21] no prospective study of swimmers has been conducted to assess a psychosocial measure.

Additional prospective studies are needed to better understand risk factors for swimming injuries, particularly in collegiate swimmers, who have been the subject of only 2 prospective studies.[2,10] Many researchers have restricted their investigations to shoulder injuries.[7–12] However, at the collegiate level, most injuries (an estimated 65% to 70%) affect body regions other than the shoulders.[3,4] Therefore, we conducted a prospective study of collegiate swimmers to determine the extent to which 4 intrinsic risk factors were associated with noncontact musculoskeletal injury throughout the body. These risk factors were previous injury, poor movement competency, erroneous freestyle swimming technique, and low perceived susceptibility to injury. We hypothesized that each risk factor would be associated with increased odds of injury.

METHODS

Participants

A total of 41 National College Athletic Association (NCAA) Division III swimmers from 1 men's team and 1 women's team took part in this prospective cohort study. We recruited participants during a preseason team meeting and included them in the study if they were ≥18 years old and medically cleared to engage in sport. We excluded those who could not speak English or provide consent. This study was conducted in parallel with another study involving the same participants in which we investigated the relationship between workload and injury.[22] We calculated the sample size for this study based on the need for a minimum of 10 injuries to perform logistic regression.[23] Given the injury incidence for the team from the previous season (27%), the calculation yielded a minimum of 37 participants. All participants provided informed consent, and the Drexel University Institutional Review Board approved this study (1806006428A001).

Procedures

During the preseason, participants completed a questionnaire on their injury history and the Perceived Susceptibility to Sport Injury (PSSI) instrument via the Research Electronic Data Capture web application (REDCap; Vanderbilt University). Excerpts of the injury history questionnaire and the PSSI questionnaire are provided in Supplemental Figures 1 and 2, respectively. The injury history questionnaire asked participants to describe all injuries they had sustained in the past 5 years for 11 body regions from head to feet. Although the injury history questionnaire has not been validated, the lead author (T.R.P.) created it with input from coauthors (M.W. and J.A.T.) with expertise in injury epidemiology. In the preseason questionnaire, participants also answered 4 questions on the PSSI.[24,25] On 5-point Likert-type scales, they rated their (1) chance of injury (belief), (2) susceptibility to injury (feeling), (3) percentage chance of injury (numeric), and (4) chance of injury compared with teammates (comparative). They also answered a question about their perceived ability to reduce risk (preventability). The sum of the responses to the first 4 questions yielded a total score for the PSSI out of 20.[24] In a previous study of collegiate student-athletes, Gnacinski et al[25] confirmed the factorial validity of the PSSI total score.

During the first week of the season, participants completed the Movement System Screening Tool (MSST), a recently developed movement competency assessment.[26] The original version of the MSST consisted of 16 component tests (MSST16). For the present study, we excluded 2 of the component tests, namely, the side bridge with active hip abduction and clinical core control test, because of poor construct validity and poor known-group validity, respectively.[26,27] We also modified the names of some MSST16 test items for the 14-item version of the MSST (MSST14) to reflect the names commonly used in the literature. In this study, participants completed the MSST14 in groups of 8 to 11 in circuit fashion. Nine physical therapists (including D.E. and S.P.S.), 4 doctoral students, and 1 undergraduate student with various degrees of experience each rated 1 component test of the MSST14. Raters underwent 1 training session with the lead author for the test they administered. During data collection, the lead author periodically audited each rater to ensure data fidelity. For the MSST16, interrater reliability was moderate to perfect for the component scores and excellent for the total score (intraclass correlation coefficient [ICC] (2,1) = 0.94; 95% CI = 0.91, 0.96).[26] Although we did not assess the reliability of our raters, previous researchers[28–30] investigating movement competency reported minimal differences in reliability among raters with various levels of experience. We administered and scored the MSST14 as described earlier.[26] We scored 7 of the component tests qualitatively on a 4-point (range = 0–3 points) ordinal scale. We scored the other 7 tests on continuous scales (eg, distance, ROM, time, and number of repetitions) and converted the scores to a 4-point (range = 0–3 points) ordinal scale based on performance relative to normative data.[26] Higher scores denoted better performance, and a score of zero denoted pain during a test, regardless of performance. Nine of the 14 tests were bilateral, yielding a maximum total score of 69 points.[26] The MSST14 testing required 1 hour per group.

Over the first month of the season, we conducted the Freestyle Swimming Technique Assessment (FSTA) during normal swim practice (Figure 1).[31] The FSTA detects the presence of 7 errors in freestyle technique that may expose the shoulder to provocative positions.[16,18] We adapted the FSTA for real-time, poolside use based on previously described methods involving above- and underwater cameras.[16,18] The test-retest reliability of the individual errors and total score have been reported as moderate (ICC [3,1] = 0.68; 95% CI = 0.43, 0.83).[31] In this study, we modified the interpretation of the arm recovery error compared with our earlier examination of reliability.[31] Given that we focused on injury risk in this study, we

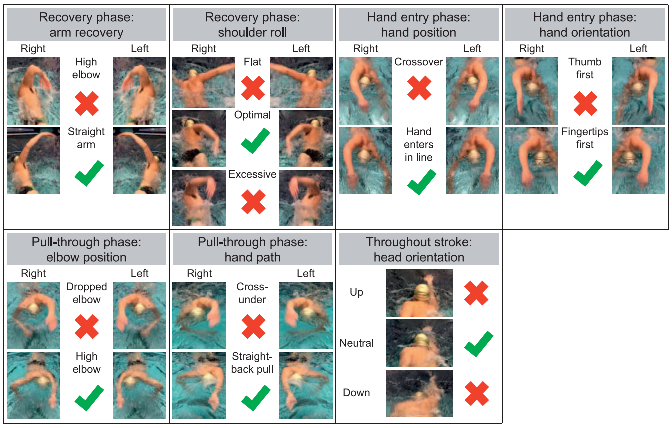

Figure 1. Errors assessed in the Freestyle Swimming Technique Assessment.

considered a high-elbow recovery to be an error. A high-elbow recovery has the potential to put the glenohumeral joint into a position of end-range internal rotation (Figure 1), whereas a straight-arm recovery (wrist higher than elbow) tends to avoid this error.[16] To minimize observer effects, participants were not aware of when they were being assessed. The lead author, a doctoral student in health and rehabilitation sciences and a former collegiate swimmer with 7 years of swimming experience, served as the rater. Six of the 7 errors were bilateral, resulting in a maximum total error score of 13.

Throughout the season, the swim coach reported injuries every 2 weeks. We defined an *injury* as any noncontact musculoskeletal pain that resulted from team activities and prevented the swimmer from participating in a competition or at least 50% of 1 practice as prescribed. Because swimmers often continue training despite pain,[17] we defined injury this way to include pain that substantially interfered with participation. This definition is comparable with the definition of interfering shoulder pain in a previous prospective study,[7] only with a precise interference threshold (50%). Injured participants (based on the coaches' report) verified the injury, mechanism, and severity via REDCap. In addition, at the midpoint and end of the season, participants described any injuries they had not reported earlier. Although electronic medical records are the norm for NCAA injury surveillance,[32] the college's athletic trainers discouraged querying their records because of the potential for underreporting. The variables collected during the 2018–2019 season are summarized in Figure 2.

Data and Statistical Analysis

We assessed differences in demographics between swimmers who did and those who did not sustain an injury using the Fisher exact test (sex and training group), Mann-Whitney *U* test (age, months per year swum, and weekly training volume), and independent-samples *t* test (height, body mass, body mass index, and swimming experience).

We investigated 4 risk factors: previous injury and total scores on the MSST14, FSTA, and PSSI. We used univariate logistic regression to assess the associations between the 4 risk factors (independent variables) and noncontact musculoskeletal injury (binary dependent variable). To ensure the relevance and severity of previous injuries, we considered only musculoskeletal injuries from the 2 years before the study, regardless of injury mechanism, that either caused in-season time loss or occurred during the off-season. We included earlier injuries from non–swimming-related activities because of their potential to affect swimming (eg, a previous anterior cruciate ligament tear affecting the breaststroke kick). We included off-season injuries to be conservative because the severity of those injuries could not be characterized based on time loss.

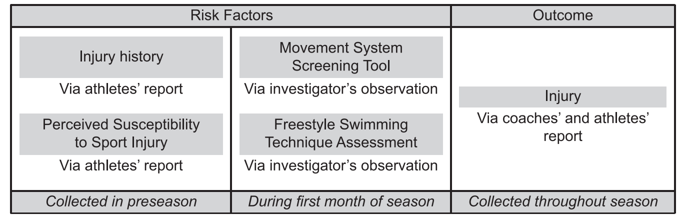

Figure 2. Overview of the risk factors and outcomes assessed over the course of the season.

To identify a subset of items that could be used to determine injury risk, we also conducted univariate logistic regression to assess the associations between each MSST14 component test, FSTA error, and PSSI question and injury. For bilateral MSST14 component tests, the lower of the scores for the left and right sides of the body constituted the component test score. We used odds ratios (ORs) with 95% CIs to compare low scores (0 or 1) with high scores (2 or 3). For FSTA errors, scores represented the number of sides on which the error was present (ie, 0, 1, or 2). We used ORs to compare an error on either or both sides (score = 1 or 2) with no error (score = 0). We treated PSSI responses (range = 1–5) as ordinal data. To assess for confounding, we calculated a point-biserial correlation coefficient (r_{pb}) to determine the correlation between previous injury and PSSI measures. For PSSI measures that were correlated with previous injury, we used multiple logistic regression to assess the possibility that prior injury confounded the association between PSSI and injury (based on a change in crude to adjusted OR of at least 10%). Additionally, we calculated the sensitivity and specificity of dichotomized risk factors that were statistically significant. The mean ± SD was used to describe normally distributed data, and the median (interquartile range [IQR]) was used to describe data that were not normally distributed. We used SPSS (version 24.0; IBM Corp) for all statistical analyses. The α level was set at .05.

RESULTS

Before the halfway point of the season, 4 participants withdrew from the team (reasons not disclosed to the researchers), leaving a sample size of 37. The swim coach reported injuries every 2 weeks. Participants returned 95% (140/148) of the 4 in-season injury questionnaires we sent via REDCap. Of the 37 participants, 11 (29.7%) sustained an injury. We found no differences in demographics, training groups, months per year swum, weekly training volume,[22] or swimming experience between swimmers who did and those who did not sustain an injury (Table 1). Seven injuries were to the shoulder (3 right, 4 left), 3 were to the

Table 1. Participant Characteristics

Variable	Student-Athletes Uninjured (n = 26)	Student-Athletes Injured (n = 11)	*P* Value
Sex, No.			.29[a]
Male	13	3	
Female	13	8	
Training group			>.99[a]
Sprint	14	6	
Mid-distance	5	2	
Distance	7	3	
Median (interquartile range)			
Age, y	19 (3)	19 (3)	.91[b]
Time swimming, mo/y	10 (3)	10 (4)	.93[b]
Training volume, km/wk	24.4 (4)	23.7 (2)	.66[b]
Mean ± SD			
Height, cm	175 ± 11	173 ± 9	.60[c]
Body mass, kg	70.2 ± 10.0	69.4 ± 13.5	.85[c]
Body mass index	22.8 ± 2.2	22.9 ± 2.8	.85[c]
Swimming experience, y	10 ± 3	12 ± 2	.12[c]

[a] Fisher exact test.
[b] Mann-Whitney *U* test.
[c] Independent-samples *t* test.

back or sacroiliac joint, and 1 was to the knee. The participants self-reported overuse mechanisms for all but 1 injury (a sacroiliac joint strain that occurred while stretching). The median number of affected participation days was 2 (range = 1 day to 2 weeks).

Injury History

On the injury history questionnaire, 14 individuals described a musculoskeletal injury in the previous 2 years (11 in-season, 3 off-season). Of those 14, 8 sustained an injury in the current season (3 to the same body region, 5 to other regions). The odds of injury in the current season were 8.89 times higher (95% CI = 1.78, 44.48) in those with an earlier injury than in those with no earlier injury. The sensitivity and specificity of previous injury for injury prediction were 0.73 (95% CI = 0.39, 0.94) and 0.77 (95% CI = 0.56, 0.91), respectively.

Movement System Screening Tool

On the MSST14, the mean ± SD score was 48 ± 8 for participants who sustained an injury compared with 45 ± 6 for injury-free participants. Neither the MSST14 total scores (OR = 1.06 [95% CI = 0.95, 1.18]) nor the component tests were associated with injury ($P > .05$; Table 2). Given that the findings at the component level were not significant, we could not identify a subset of component MSST tests for injury-risk appraisal.

Freestyle Swimming Technique Assessment

On the FSTA, the mean ± SD score was 4 ± 1 for individuals who sustained an injury compared with 3 ± 2 for injury-free individuals. The FSTA total scores were not associated with injury (OR = 1.26 [95% CI = 0.79, 2.01]). However, swimmers who exhibited a crossover hand position during the hand-entry phase of the freestyle stroke (n = 9; 4 unilateral, 5 bilateral) on 1 or both sides had higher odds of injury (OR = 8.50 [95% CI = 1.50, 48.05]) than swimmers whose hands entered the water lateral to their midline. The sensitivity and specificity of the crossover hand position for injury prediction were 0.82 (95% CI = 0.48, 0.97) and 0.65 (95% CI = 0.44, 0.83], respectively. None of the other FSTA errors were associated with injury ($P > .05$; Table 3).

Table 2. Associations Between the 14-Item Movement System Screening Tool Total Score and Component Tests and Noncontact Musculoskeletal Injury

Risk Factor	Score	Odds Ratio (95% CI)
Total score	0–69	1.06 (0.95, 1.18)
Active straight-leg raise	0, 1	0.33 (0.04, 3.16)
	2, 3	Referent
Unilateral hip-bridge endurance	0, 1	1.14 (0.28, 4.70)
	2, 3	Referent
Rotary stability[a]	NA	NA
Trunk flexion and extension mobility	0, 1	0.51 (0.11, 2.38)
	2, 3	Referent
Shoulder mobility	0, 1	1.55 (0.35, 6.98)
	2, 3	Referent
Glenohumeral internal rotation deficit	0, 1	0.71 (0.17, 2.94)
	2, 3	Referent
Scapular dyskinesis	0, 1	2.06 (0.38, 11.31)
	2, 3	Referent
Hurdle step[a]	NA	NA
Closed kinetic chain upper extremity stability test	0, 1	1.57 (0.38, 6.62)
	2, 3	Referent
Deep squat[b]	0, 1	1.02 (0.21, 4.97)
	2, 3	Referent
Double-legged lowering test	0, 1	0.71 (0.17, 2.94)
	2, 3	Referent
Step-down	0, 1	0.11 (0.01, 1.18)
	2, 3	Referent
Single-legged hop for distance[b]	0, 1	0.44 (0.11, 1.85)
	2, 3	Referent
Y-Balance test: anterior reach[b]	0, 1	0.42 (0.04, 4.09)
	2, 3	Referent

Abbreviation: NA, not applicable.
[a] Insufficient variability in scores to compute (see Supplementary Table 1 for score frequencies).
[b] The name of the instrument[26] item was modified for the Movement System Screening Tool 14 to reflect the name commonly used in the literature.

Perceived Susceptibility to Sport Injury

The mean ± SD PSSI score was 11 ± 3 for participants who sustained an injury compared with 12 ± 3 for injury-free participants. Neither the PSSI total score (OR = 0.94 [95% CI = 0.74, 1.19]) nor any of the individual PSSI item scores were associated with injury in univariate models ($P > .05$; Table 4). However, we observed correlations between previous injury and PSSI total score ($r_{pb} = 0.34$, $P = .03$) and previous injury and PSSI score ($r_{pb} = 0.42$, $P = .01$). After adjusting for previous injury, we still found no association between the PSSI total score and injury (adjusted OR = 0.75 [95% CI = 0.54, 1.06]). Nonetheless, in the adjusted model, swimmers with higher numeric PSSI scores had decreased odds of injury (adjusted OR = 0.11 [95% CI = 0.02, 0.82]). Expressed in the reciprocal, in the adjusted model, swimmers with lower numeric PSSI scores had increased odds of injury (adjusted OR = 8.80 [95% CI = 1.21, 63.71]).

Table 3. Associations Between the Freestyle Swimming Technique Assessment Total Score and Individual Errors and Noncontact Musculoskeletal Injury

Risk Factor	Score	Odds Ratio (95% CI)
Total score	0–13	1.26 (0.79, 2.01)
Recovery phase		
Arm recovery	1, 2	1.82 (0.18, 18.41)
	0	Referent
Shoulder roll	1, 2	1.14 (0.28, 4.70)
	0	Referent
Hand-entry phase		
Hand position	1, 2	8.50 (1.50, 48.05)[a]
	0	Referent
Hand orientation	1, 2	0.60 (0.13, 2.81)
	0	Referent
Pull-through phase		
Elbow position[b]	NA	NA
Hand path	1, 2	0.27 (0.03, 2.53)
	0	Referent
Throughout stroke: head orientation[a]	NA	NA

Abbreviation: NA, not applicable

[a] $P < .05$.

[b] Insufficient variability in scores to compute (see the Supplemental Table 2 for error prevalence).

Table 4. Associations Between Perceived Susceptibility to Sport Injury Total Score and Individual Questions and Noncontact Musculoskeletal Injury

Risk Factor	Score	Odds Ratio (95% CI)
Total score[a]	1–20	0.94 (0.74, 1.19)
Belief	1–5	0.48 (0.19, 1.22)
Feeling	1–5	0.87 (0.39, 1.92)
Numeric	1–5	0.73 (0.29, 1.86)
Comparative	1–5	1.19 (0.63, 2.27)
Preventability	1–5	2.07 (0.77, 5.56)

[a] Sum of the belief, feeling, numeric, and comparative scores.

DISCUSSION

The purpose of our study was to determine the extent to which prior injury, poor movement competency, erroneous freestyle technique, and low PSSI score were associated with noncontact musculoskeletal injury in collegiate swimmers. Compared with epidemiologic data on collegiate swimmers, the injuries recorded (to the shoulder, back or sacroiliac joint, and knee) align with national estimates of the most frequently injured body regions.[3,4] Our hypothesis regarding the risk factors for these injuries was partially supported. Swimmers with a previous injury had almost 9-times higher odds of an injury. Although the total scores on the MSST14, FSTA, and PSSI were not associated with injury, swimmers who exhibited a crossover hand position during the hand-entry phase of the freestyle stroke had 8.5-times higher odds of injury. In addition, after adjusting for earlier injury, we noted that a lower perceived percentage chance of injury was associated with increased odds of injury.

Injury History

Our observation that previous injury was a risk factor for injury confirms the results of 2 prior prospective studies: one in Division I collegiate swimmers and the other in club swimmers.[2,7] This finding has both simple and complex ramifications. Identifying athletes with an earlier injury is straightforward. In this study, we used a comprehensive injury history questionnaire. For collegiate swimmers, preseason meetings with student-athletes or injury-surveillance records (where comprehensive) could also provide this information. The challenge lies in determining how to manage swimmers with previous injuries. For example, coaches and sports medicine teams can ensure full rehabilitation of those injuries,[33,34] prescribe targeted prevention exercises for the swimmers,[5] and closely monitor training and competition workloads.[22]

Movement System Screening Tool

Poor movement competency based on the MSST14 was not a risk factor for injury. In a cross-sectional study of the MSST16, researchers[26] determined that 40 athletes with nontraumatic shoulder injuries scored a mean $\pm$ SE of 5.8 $\pm$ 1.2 points lower on the MSST16 than 40 matched pairs. However, using that cross-sectional design, it was not possible to identify whether the observed deficits were a cause or result of the injuries. In addition, although the cross-sectional study sample involved 8 swimmers, it also included athletes from $>$12 other sports.[26] Unlike their land-based counterparts, swimmers perform most of their training immersed in water, in a non–weight-bearing horizontal body position, and rely on their upper extremities for propulsion. In this aquatic environment, swimmers undergo unique biomechanical, physiological, and perceptual demands. From a specificity standpoint, movement competency on land may contribute little to the injury risk in swimmers.

As related to the shoulder, the authors of prospective studies of swimmers demonstrated relationships between injury and limited extension ROM[10] and strength,[8] external-rotation ROM[7] and strength ratio (with respect to internal rotation),[11] and horizontal abduction ROM[9] and endurance.[12] Conversely, we found no associations between injury and any of the shoulder-related MSST component tests (shoulder mobility, glenohumeral internal-rotation deficit, scapular dyskinesis, and the closed chain upper extremity stability test).[26] These conflicting results could reflect differences in the tests as well as the ages of study participants. All of the earlier studies included swimmers younger than college age.

Freestyle Swimming Technique Assessment

Although movement competency on land was not a risk factor for injury, 1 error in freestyle stroke technique did increase the odds of injury, namely, a crossover hand entry. The crossover hand entry is similar to the provocation position in the Neer test for shoulder impingement. Of the 11 swimmers who sustained injuries, 9 exhibited this technique error. However, 9 participants swam with a crossover hand entry and did not sustain an injury. Thus, this technique error appears to be more sensitive than specific for predicting injury, which is a desirable property for a screening test. The observed variability in injury response could be because of structural and functional differences in swimmers' shoulders.[16] The morphology of some swimmers' shoulders may permit pain-free movement through this ROM, whereas for others, the extreme repetition irritates the subacromial structures.

The relationship between a crossover hand entry and injury in our investigation appears to conflict with prior results.[12] In that research, swimmers who made a hand-entry error had unexpectedly lower odds of injury (OR = 0.37 [95% CI = 0.16, 0.91]) than swimmers who did not make the error.[12] Yet in addition to the crossover hand-entry position, the authors considered a lateral entry position to be erroneous.[12] In contrast, we did not consider a lateral entry position erroneous. A lateral entry may be suboptimal from a performance standpoint. Still, unlike the medial crossover, the lateral entry does not put the shoulder in the provocative end-range position that has been implicated in swimmer's shoulder.[1] This difference in rating systems between studies may account for the conflicting findings. Despite the high prevalence of other freestyle technique errors, none were associated with injury in this or the earlier investigation.[12] These findings include techniques that coaches and researchers have long considered risky, such as a thumb-first hand entry and a cross-under pull-through.[18] Thus, apart from the hand position at entry, regarding injury risk, a variety of freestyle techniques may be acceptable. Coaches should evaluate technique on an individual basis relative to each swimmer's unique musculoskeletal profile.[16]

Perceived Susceptibility to Sport Injury

We are the first to prospectively examine the association between the numeric PSSI score and injury. After we adjusted for previous injury, for every 1-point decrease in PSSI score, the odds of injury increased almost 9-fold. Our finding aligns with the Health Belief Model, which posits that if athletes perceive their injury risk to be low, they may be less likely to engage in injury-prevention activities, which actually increases their risk.[24] The authors of 2 earlier studies evaluated similar constructs with mixed results. In 1 study,[35] youth soccer players with a lower perceived risk of injury (based on the Perceived Risk of Injury in Sports Scale) had higher odds of injury. However, in the other,[36] cadet candidates with a greater self-reported concern for injury (on a 3-point scale) had higher odds of injury. The heterogeneity of findings may be attributable to differences in measurement instruments or populations studied or failure to control for prior injury, which has been shown to increase the PSSI score.[24]

Limitations and Recommendations for Future Research

We based injury history and injury over the course of the season on the reports of student-athletes and coaches, not electronic medical records. We chose this approach to capture all episodes of interfering pain, including those that affected the participants' ability to train and compete but did not cause them to seek medical attention. Self-report does introduce the potential for bias, which we mitigated by limiting the injury history to the past 2 years and cross-referencing the injury reports of coaches and student-athletes.

Additionally, our sample was limited to student-athletes from 1 men's and 1 women's NCAA Division III team and 1 season. As such, our results may not be generalizable to swimmers at other competitive levels or swimmers pursuing substantially different workloads. Furthermore, this sample size prevented us from assessing the possible interaction of risk factors in a multifactorial model. It also resulted in wide CIs surrounding the ORs. Therefore, readers should interpret the magnitudes of the observed associations with caution. Moreover, based on the small sample size, a type II error may have obscured the associations between some risk factors and injury. For example, our study was underpowered to detect associations with injury for the scapular dyskinesis test (a component test of the MSST) and the PSSI preventability question, which both had ORs of >2.0 (Tables 2 and 4, respectively). Nevertheless, we detected associations between crossover hand entry and numeric PSSI score and injury. These associations represent novel findings in an understudied athlete population.

To reduce the risk of type II error and further improve our understanding of risk factors for injury in swimmers, additional larger-scale studies on multiple teams or across multiple seasons (or both) are needed. Future intervention studies are also warranted to assess the effects of (1) tertiary prevention exercises plus education for swimmers with previous injuries (to make them more aware of their increased risk) and (2) modification of the crossover hand-entry position in freestyle.

CONCLUSIONS

We reaffirmed prior injury as a risk factor for noncontact musculoskeletal injury in competitive swimmers. We also identified another risk factor that heretofore had been largely theoretical, namely, a crossover hand position during the entry phase of the freestyle stroke. Contrary to our hypothesis, no other characteristic of freestyle technique was associated with injury, and neither the MSST14 nor any component test thereof was associated with injury. Although limited by a small sample size, given the lack of association between the MSST14 total and component test scores and injury, our data do not support using the MSST14 to appraise swimmers' injury risk. Finally, after we adjusted for previous injury, a low numeric PSSI score was a risk factor for injury. Coaches and sports medicine practitioners should focus on gathering thorough injury histories on their swimmers. Swimmers with earlier injuries may benefit from tertiary prevention exercises as well as education on prior injury as a risk factor for reinjury or new injury. Coaches should also continually audit swimmers' freestyle technique for the crossover hand-entry position. To appraise the injury risk comprehensively, coaches should consider these intrinsic risk factors in conjunction with extrinsic risk factors, including workloads.[22]

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Address correspondence to Travis Pollen, PhD, Physical Therapy and Rehabilitation Sciences, College of Nursing and Health Professions, Drexel University, 1601 Cherry Street, Philadelphia, PA 19102. Address e-mail to travis.pollen@jefferson.edu.