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An investigation of scapular dyskinesis in recreational surfers and non-surfers

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SUMMARY

Recreational surfers frequently present with shoulder injuries yet there has been little research into factors that might increase injury risk in this population.
Objectives: The purpose of this study was to compare the presence of scapular dyskinesis in a group of surfers and non-surfers.
Design: Cross-sectional.
Methods: A total of 215 participants (108 surfers, 107 non-surfers) were video recorded while performing unweighted, bilateral shoulder flexion and abduction. Videos were assessed by three clinicians to evaluate scapular dyskinesis. Participants were grouped along several different variables including age, sex, participation in other overhead sports, pain, dominant arm, injury history, skill level, surf experience, and the percent of participants exhibiting scapular dyskinesis was calculated for each category.
Results: Surfers and non-surfers both presented with 48% positive scapular dyskinesis tests (OR = 1.018, 95% CI: 0.596–1.738). No significant differences were detected among groups divided along any of the variables analyzed. Percentage of agreement between clinicians was 72% (Fleiss' kappa = 0.46).
Conclusions: These findings suggest that recreational participation in the sport of surfing has a minimal impact on the likelihood of exhibiting scapular dyskinesis. The interrater reliability of an assessment protocol using video recordings was fair to moderate.

1. Introduction

Recent studies have reported that between 19 and 27% of traumatic and gradual onset surfing injuries occur at the shoulder joint [1–3]. Repetitive paddling may contribute to shoulder injury in these athletes, due to the volume of activity and external load placed on the upper extremity [3]. Surfers spend approximately 45–60% of a surfing session paddling and have been reported to cover distances up to 5 km [4,5]. Gradual onset shoulder injury is also related to surfing experience, surfer's age, and frequency of surfing, which further suggest that paddling volume and cumulative activity may contribute to injury [3,6]. Chronic shoulder injuries in surfers are more likely to persist for durations greater than 3 months and do not resolve without medical intervention [2,7]. Surfers frequently present with shoulder instability (48%), rotator cuff tears (42%) and labral tears (35%) [2], and when compared to other injury sites, the shoulder was most likely to require surgical repair [2,5].

Efficient and stable motion at the shoulder requires coordinated and coupled movement between the scapula and humerus [8,9]. The cumulative effect of improper coordination between the scapula and humerus (i.e. scapular dyskinesis) during repetitive movements like the surf paddling stroke may contribute to gradual onset injury. During abduction, for example, alterations in the ratio of scapular upward rotation to glenohumeral elevation can impact the forces that occur within the glenohumeral joint [8]. Further, there is evidence of a relationship between scapular dyskinesis and shoulder pain and injury in both the athlete and the general population [9,10]. There is also evidence of the predictive value of scapular dyskinesis, as overhead athletes presenting with abnormal scapular motion were reportedly more likely to suffer a

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future shoulder injury [9,11]. Finally, the prevalence of scapular dyskinesis has been reported to be greater among several types of overhead athletes when compared to control groups or athletes that do not typically engage in overhead motion [12–15].

In contrast to these studies, there is also evidence that scapular dyskinesis is not associated with shoulder pathology. For example, multiple studies have reported little to no differences in the prevalence of scapular dyskinesis in individuals with and without shoulder pain [16,17]. This disagreement may be attributed to the fact that scapular dyskinesis is not itself an injury, but is more accurately described as an impairment [18]. It may also be mistaken for normal variation in scapular motion that can occur at a joint with several degrees of freedom, since there can be multiple effective movement strategies to achieve a particular movement related goal [19,20]. Therefore, it is most informative when a clinician can associate the presence of scapular dyskinesis with a potential mechanism or cause. In such cases, scapular dyskinesis may not be clinically relevant unless it can be determined to be problematic.

A potential mechanism behind scapular dyskinesis has been proposed for surfers [7]. During the paddling motion, surfers generate forceful muscle contractions by latissimus dorsi and pectoralis major for propulsion, both of which are internal rotators of the shoulder [19,21]. Other shoulder internal rotators (subscapularis, pectoralis minor, teres major, and anterior deltoid) likely contribute to propulsion as well. During the recovery phase of the stroke, the external rotators of the shoulder (posterior deltoid, infraspinatus, and teres minor) are only resisted by gravity because the arm is lifted out of the water. This imbalance in resistance between different phases of the paddling stroke, over time, may lead to external rotation deficit [7]. Surfers have been shown to exhibit greater internal rotation strength and reduced external to internal rotation strength ratios when compared to other non-overhead athletes [7,22,23]. Surfers also develop shorter internal rotator muscles as evidenced by changes in external rotation range of motion [6,7]. Scapular dyskinesis might occur as a result of this condition through multiple mechanisms, including a shortened pectoralis minor leading to malposition of the scapula through excessive anterior tilt and protraction [24]. A weakened serratus anterior may further exacerbate this condition through reduced posterior tilt [24]. Further, shortened internal rotator muscles combined with weak external rotator muscles can also lead to a narrowing of the subacromial space and subsequent impingement [25]. Individuals with impingement were reported to have a more downward rotated and anterior tilted scapula, and often demonstrate more asymmetry in scapular motion when compared to healthy individuals [26].

To date, no one has investigated scapular dyskinesis in surfers. Therefore, the purpose of this study was to evaluate the prevalence of scapular dyskinesis in a group of recreational surfers and non-surfers. Based upon literature reporting higher prevalence of scapular dyskinesis in overhead athletes [12–15], as well as potential mechanisms of shoulder overuse injury in surfers [6,7,22,23], it was hypothesized that scapular dyskinesis would be observed with greater frequency in individuals with a history of participation in the sport of surfing. Findings from this investigation may be useful in identifying mechanisms of shoulder injury in surfing or identifying individuals who may be at risk for overuse injury.

2. Materials and methods

2.1. Participants

This was a cross-sectional study in which two hundred fifteen participants were recruited from San Diego County beaches and the local population in and around California State University, San Marcos. One hundred and eight participants were surfers (83 male, 22 female) with an average age of 32.5 ± 12.9 years. Participants were excluded if they were less than 18 years or greater than 65 years of age. Surfers were included if they had surfed at least once in the past week. One hundred and seven participants were non-surfers (65 male, 42 female) with an average age of 29.4 ± 11.6 years. Participant groups were not matched along any variable, including age, sex, dominant arm, or prior injury. Additional relevant participant characteristics are included in Table 1. All procedures were determined to be exempt from review by the Institutional Review Board at California State University, San Marcos (IRB#1383259–1) because the identity of participants cannot be readily ascertained through the video recordings or survey data. However, verbal consent was obtained from all participants prior to initiating the evaluation protocol. Participants also completed a survey with self-reported history of shoulder pain and injury, participation in other overhead sports, surfing experience, and surfing skill level as applicable.

2.2. Protocol

The testing protocol utilized a well-known visual assessment of scapular motion from a posterior view of the participant [27,28]. All participants were video recorded while performing three repetitions each of bilateral shoulder flexion and abduction. Visual observation of shoulder flexion and abduction have been sufficient in identifying dyskinesis due to the potential observation of dysrhythmia or winging [27]. Participants were instructed on how to perform both movements and a visual demonstration was provided. No external weight was held by participants during these movements. Male participants were instructed to remove their shirt prior to video recording. Female participants performed these motions while wearing a sports bra or bathing suit top. Videos were recorded using GoPro Hero-4 cameras (GoPro, Encinitas, CA, USA) and a basic tripod for stability. Filming occurred at various locations including in the field (at the beach) and on campus in a private room. Surfers were filmed either before the surf session or afterward, and this variable was recorded for future analysis since prior research indicates that the likelihood of exhibiting scapular dyskinesis increases in real time with participation in activity [14,15]. No participant faces were recorded, but videos were identified by writing the participant number on a small index card within the camera's field of view.

Three Physical Therapists (PTs) independently viewed all videos online and assessed whether scapular dyskinesis was present in any of

Table 1
Participant characteristics.

		Surfers	Non-Surfers
Participants (n)		108	107
Age (years)	*mean ± SD*	32.5 ± 12.9	29.4 ± 11.6
	range	18–65	19–65
	median	27	24
Height (m)	*mean ± SD*	1.76 ± 0.1	1.72 ± 0.1
	range	1.32–2.11	1.45–1.93
	median	177.8	170.2
Mass (kg)	*mean ± SD*	72.8 ± 13.6	74.7 ± 17
	range	45.6–113.3	43.0–126.9
	median	73.6	77.0
Participants That Play Other Overhead Sports		31	51
Participants That Reported Pain in Last 2 Weeks		30	23
Participants That Reported a Prior Shoulder Injury		48	40
Average Surf Skill (1–10)	*mean ± SD*	5.7 ± 2.6	
	range	0–10	
	median	6	
Average Surfing Experience (years)	*mean ± SD*	13.1 ± 12.7	
	range	0–50	
	median	10	
Hours Surfed per Week	*mean ± SD*	4.4 ± 4.3	
	range	0–21	
	median	2.8	
Assessed Prior/After Surf Session		70/28	

the movements and in either (or both) shoulders. Each PT was instructed to look for 1) lack of coordination in scapula-humeral rhythm, 2) excessive shrugging or scapular elevation, 3) excessive scapular anterior tipping, or 4) excessive scapular winging. Prior to formally assessing all videos, each PT participated in a practice session in which they evaluated the same ten videos and then compared and discussed their evaluations. This process improved agreement and consensus in their interpretation of scapular dyskinesis. The three PTs were blinded to the results of the other raters as they assessed the remaining videos. The PTs were not explicitly informed as to whether each video was from a surfer or non-surfer but were informed that videos recorded at the beach did not necessarily indicate that the participant was a surfer. However, some participants could be seen wearing wetsuits over their lower body, which would be a strong indication that they were surfers. The assessment used here was adapted from the procedure outlined in [28] in which clinicians rated each individual motion at each shoulder as 0 (no dyskinesis), 1 (mild dyskinesis) or 2 (moderate to severe dyskinesis) (Fig. 1). Prior investigations of the reliability of this evaluation have indicated that a three-tier classification method can result in lower reliability when compared to a simple positive/negative assessment [10,13,14,29]. Therefore, all scores of 0 were considered negative and all scores of 1 or 2 were considered positive for this analysis. Participants who exhibited scapular dyskinesis for only a single motion (abduction or flexion) or for a single shoulder were classified as positive. For cases where clinician ratings did not agree, the final rating was determined by majority.

2.3. Data analysis

All participants were categorized along several different binary variables with resampling for each variable, and relevant statistics were calculated for each grouping. These groupings included: surfers and non-surfers, younger age and older age, male and female, shoulder pain and no shoulder pain, history of shoulder injury and no history, and participation in other overhead sports. In addition, the surf group was parsed into those with less experience and greater experience, low skill level and higher skill level, and whether they were evaluated before or after their surf session. The dominant vs non-dominant arm of each participant was also compared. Participants who were above the median age of 25 were grouped into the older group and those 25 years or below were grouped into the younger group. Surfing skill level was self-reported on the questionnaire using a scale of 1–10. For analysis, surfers were split into those with a score of 1–6 and those with a score of 7+ based on the median reported score of 6. Lastly, surf experience in years was also self-reported, and for analysis was split into groups with 0–10 years of experience and those with greater than 10 years of experience. Presence of shoulder pain was defined as any pain experienced while surfing, while performing the test, or at any time in the last 2 weeks. Participants self-reported their shoulder injury history, which resulted in a broad range of injury mechanism and severity, as well as time since injury. Descriptive data are presented in Table 1.

Descriptive statistics were calculated for each group, including the percent of individuals determined to have presented with scapular

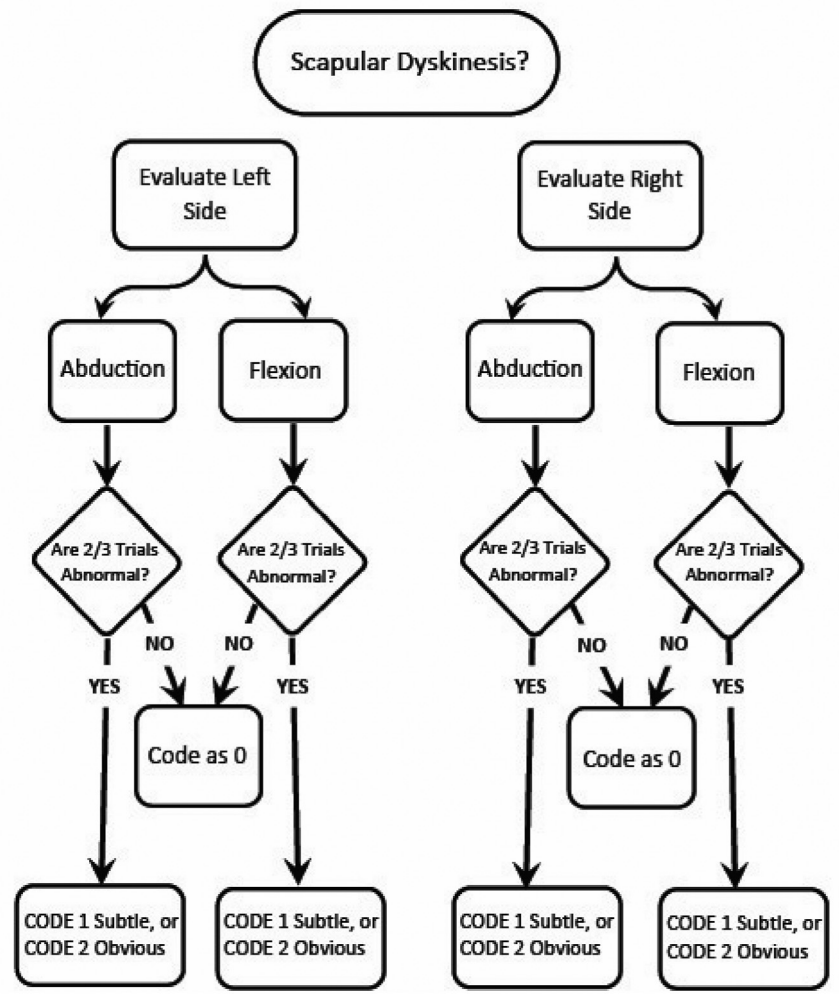

Fig. 1. Flowchart representing the process that each clinician followed when evaluating each video for scapular dyskinesis. Each video included three trials each of bilateral shoulder flexion and abduction.

dyskinesis. The distribution of positive assessments among groups was evaluated by comparing the observed frequencies to expected frequencies using simple Chi-Square analysis. Odds ratio (OR) with 95% CI were also calculated for each variable analyzed. Reliability among the three clinicians was analyzed by calculating percent agreement and using Fleiss' Kappa [30].

3. Results

Participant characteristics are provided in Table 1. Analysis for normality using Shapiro–Wilk revealed that none of the descriptive data exhibited a normal distribution, with the exception of height for the non-surf group. Chi-square analysis indicated that the observed frequency of positive tests for scapular dyskinesis did not differ from the expected frequency for any of the variables compared (Tables 2 and 3, Figs. 2 and 3). Similarly, odds ratios were relatively close to one for all analyses (Tables 2 and 3). Clinicians were unanimous in their assessment for 128 of 215 participants and demonstrated an overall percent agreement among all movements and shoulders of 72%. Fleiss' Kappa (k) was equal to 0.458 (moderate strength) for positive/negative evaluation and 0.281 (fair strength) for the three-tiered categorization of no dyskinesis, mild/subtle dyskinesis, and moderate/severe dyskinesis.

4. Discussion

The purpose of this study was to compare the prevalence of scapular dyskinesis between surfers and non-surfers, since it has been proposed that surfers may develop a muscular imbalance at the shoulder that can lead to abnormal scapular motion. The prevalence of scapular dyskinesis was also compared along several other variables including age, sex, dominant arm, shoulder pain, and a history of shoulder injury. The data indicated that there were no significant differences in the prevalence of scapular dyskinesis for any of the comparisons made here, including surfers and non-surfers (Tables 2–3, Figs. 2 and 3). The odds ratio for participation in surfing was very close to one (1.018, 95% CI: 0.596–1.738), suggesting that recreational participation in the sport of surfing has a minimal impact on the risk of exhibiting scapular dyskinesis. Interrater agreement among three practicing clinicians was moderate for a positive/negative evaluation (k = 0.458) but fair for evaluation using a three-tiered scale (k = 0.281).

The number of surfers and non-surfers who exhibited scapular dyskinesis did not differ from expected frequencies, as determined by Chi-square analysis (Table 2). This result did not support the hypothesis that surfers would exhibit scapular dyskinesis with greater frequency. This hypothesis was based on prior reports of internal and external rotator strength imbalances in surfers as a potential mechanism for chronic shoulder injury and a factor in abnormal scapular motion [6,7,22,23]. It was also based upon prior work that reported a greater prevalence of scapular dyskinesis in overhead athletes (such as swimmers) when compared to individuals that do not typically engage in overhead motion [12–15,31]. One potential explanation for the current results may be that many recreational surfers do not surf frequently enough on average to develop significant internal (IR) and external rotation (ER) muscular imbalances at the shoulder. All prior studies that examined ER/IR strength and external rotation range of motion were performed on a mix of competitive (n = 26 total) and recreational (n = 17 total) surfers and did not compare these measurements between different levels of surfer [6,22,23]. However, Lassalle et al. (2012) reported that surfers who reported shoulder pain surfed for more than twice as many hours per week when compared to surfers without pain (15±6h vs 6.5±4h) [6]. Participants in the current study reported an average of only 4.4 ± 4.3 h surfed per week, which may be below the threshold for developing muscle imbalance and scapular dyskinesis. Future research should examine more broadly the prevalence of external rotator strength and/or range of motion deficits, and whether they are more likely to occur in those who surf more frequently. If deficits are primarily detected in competitive surfers, it may help to explain why the prevalence of scapular dyskinesis was not elevated in the recreational surfers studied here.

These results may also be related to participation in other overhead sports. Since a greater number of non-surfers indicated that they

Table 2
Statistical results for entire sample (n = 215).

	χ^2	p-value	Odds Ratio	Odds Ratio 95% CI
Surf vs. Non-Surfers	0.004	0.947	1.018	0.596, 1.738
Overhead Sport Participation	0.961	0.327	1.141	0.657, 1.979
Age	0.078	0.780	0.927	0.542, 1.584
Shoulder Pain	0.664	0.415	1.292	0.697, 2.392
Male vs Female	0.324	0.569	0.881	0.493, 1.576
Dominant Arm	0.095	0.758	0.919	0.613, 1.376
Prior Injury	0.072	0.789	0.928	0.537, 1.605

Table 3
Statistical results for surfers only (n = 108).

	χ^2	p-value	Odds Ratio	Odds Ratio 95% CI
Measured Before/After Surf Session	0.172	0.678	0.832	0.350, 1.980
Surf Years of Experience	0.000	1.000	1.000	0.470, 2.127
Surf Skill Level	0.148	0.700	0.862	0.405, 1.835
Age (surfers only)	0.326	0.568	1.246	0.585, 2.654

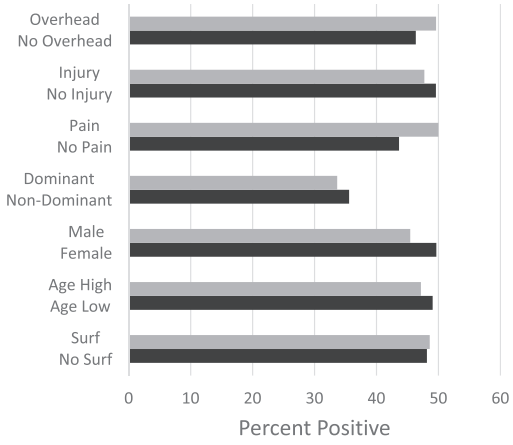

Fig. 2. Percent of individuals in each category who exhibited scapular dyskinesis while performing bilateral shoulder flexion and abduction. All participants (n = 215) are included in these results.

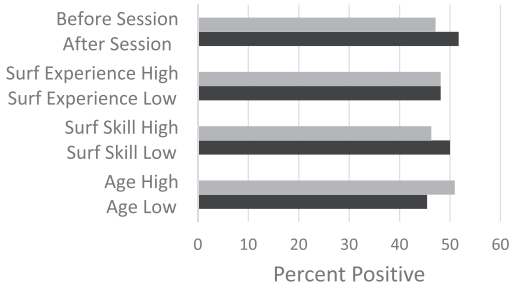

Fig. 3. Percent of surfers in each category who exhibited scapular dyskinesis while performing bilateral shoulder flexion and abduction. Only surfers (n = 108) are included in these results.

participated in other overhead sports (28.7% vs 47.7% Table 1), this may have contributed to an increase in the prevalence of scapular dyskinesis in the non-surfing group. Prior studies in surfers have not examined whether athletes participate in other overhead sports and how this may impact shoulder function [7,22,23]. It is generally assumed that participation in overhead sports places individuals at greater risk for injury, and athletes who participate in these sports have been reported to be more likely to exhibit scapular dyskinesis [12–15,31]. However, this relationship may be more complicated in surfers as participation in additional sports may help to counteract potential muscular adaptations caused by repetitive paddling.

The current results may also be related to limitations associated with this method of assessment. While visual observation of scapular motion has been used in prior studies [13–15,27–29], it is not as sensitive or specific as quantitative assessments for scapular dyskinesis such as modified scapulometer, inclinometer, caliper, and the Palpation Meter [29]. Therefore, some participants in this study may have been mis-categorized, particularly in cases where scapular dyskinesis was subtle. In addition, anterior tilt and winging of the scapula are motions that occur primarily in the sagittal and transverse planes and may have been difficult to evaluate from the vantage point of a single camera recording directly from behind the surfer. Initial pilot testing included a push-up test to assist with evaluation of scapular winging, but it was determined that this action did not improve discrimination of excessive scapular winging from the video analysis. Finally, while there was moderate agreement among clinicians reviewing the video, unanimous agreement was reached in only 72% of the participants. This corresponds with a fair to moderate agreement based upon Fleiss' kappa ($k = 0.458$). Prior studies of the scapular dyskinesis test have reported kappa values ranging from $k < 0.4$ [10,13] to $k > 0.6$ [28]. Future study of scapular dyskinesis in surfers should utilize more sensitive and detailed assessment of scapular motion [29].

The current data indicate that there was a slight increase in the prevalence of scapular dyskinesis in individuals with shoulder pain (43.6% vs 50.0%, Odds Ratio 1.292, 95% CI 0.697, 2.392). Though not statistically significant, this result is consistent with other studies that have also reported a relationship between shoulder pain and scapular dyskinesis [9,10]. However, it should be noted that there was an imbalance of individuals with shoulder pain in the surf and non-surf group (27.8% vs 21.5%, respectively). Individuals with shoulder pain who had just finished surfing may have been more likely to exhibit scapular dyskinesis. Conversely, individuals with a history of shoulder injury in the current study did not exhibit a difference in prevalence of scapular dyskinesis (49.6% no injury vs 47.7% injury, Odds Ratio 0.928, 95% CI 0.537, 1.605). This result is consistent with some prior research [16], but is inconsistent with other studies that have reported a stronger relationship between injury and scapular dyskinesis [10]. Finally, other studies have reported a difference in prevalence of scapular dyskinesis between the dominant and non-dominant arm [31], but there appeared to be little difference in surfers (35.6% dominant vs 33.7% non-dominant, Odds Ratio 0.919, 95% CI: 0.613, 1.376). While many other overhead sports require greater use of the dominant arm for throwing and hitting, most swim strokes and the surf paddling motion are bilateral and symmetrical.

There was a small difference in prevalence of scapular dyskinesis between those who were assessed prior vs after their surf session (Table 3, Fig. 3). This may have been an artifact of a small sample size and unequal distribution between groups (70 before vs 28 after). Swimmers were more likely to exhibit scapular dyskinesis as they were evaluated early vs later in a single practice session, suggesting that there may be a relationship between muscle fatigue and scapular dyskinesis [14,15]. While the current data for surfers did not exhibit a statistically significant effect, there was a slightly greater prevalence in the group that was assessed after their session (47.1% before vs 51.7% after, Odds Ratio 0.832, 95% CI 0.350, 1.980). Future study of scapular dyskinesis in surfers should account for the potential effects of muscular fatigue.

In summary, these data indicate that surfers are not at greater risk for exhibiting scapular dyskinesis. In addition, no significant differences were noted for any other variable analyzed here including age, sex, dominant arm, history of shoulder injury, and pain. Moderate interrater reliability was found for the assessment of scapular dyskinesis from video recordings of bilateral shoulder flexion and abduction. These results may be generalized to the average recreational surfer who surfs with a frequency less than 5 h per week. Future study of shoulder function in surfers should focus on the prevalence of muscular strength imbalance and shortening (e.g. pectoralis minor, latissimus dorsi, and subscapularis), particularly among competitive vs. recreational surfers with differing levels of surfing frequency, as this may help to explain the mechanisms that contribute to shoulder injury in this population. To further validate the findings of the current study, future analysis of scapular dyskinesis should incorporate more sensitive and reliable measures of scapular motion.

Ethical approval

All procedures were determined to be exempt from review by the Institutional Review Board at California State University, San Marcos (IRB#1383259–1) because the identity of participants cannot be readily ascertained through the video recordings or survey data. However, verbal consent was obtained from all participants prior to initiating the protocol.

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Declaration of competing interest

None

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References

[1] Furness J, Hing W, Abbott A, Walsh J, Sheppard JM, Climstein M. Retrospective analysis of chronic injuries in recreational and competitive surfers: injury location, type and mechanism. Int J Aquat Res Educ 2014;8(3):277–87. https://doi.org/10.1123/ijare.2013-0032.

[2] Hohn E, Robinson S, Merriman J, Parrish R, Kramer W. Orthopedic injuries in professional surfers: a retrospective study at a single orthopedic center. Clin J Sport Med 2020;30(4):378–82. https://doi.org/10.1097/JSM.0000000000000596.

[3] Remnant D, Moran RW, Furness J, Climstein M, Hing W, Bacon CJ. Gradual-onset surfing-related injuries in New Zealand: a cross-sectional study. J Sci Med Sport 2020;23(11):1049–54. https://doi.org/10.1016/j.jsams.2020.05.010.

[4] LaLanne CL, Cannady MS, Moon JF, Taylor DL, Nessler JA, Crocker GH, et al. Characterization of activity and cardiovascular responses during surfing in recreational male surfers between the ages of 18-75 years old. J Aging Phys Activ 2016;25(2):182–8. https://doi.org/10.1123/japa.2016-0041.

[5] Furness J, McArthur K, Remnant D, Jorgensen D, Bacon CJ, Moran K, et al. Traumatic surfing injuries in New Zealand: a descriptive epidemiology study. PeerJ 2021. https://doi.org/10.7717/peerj.12334.

[6] Lassalle C, Andre F, Millas P, Hugues Y, Messina M, Lougarot S, et al. Characteristics of the painful surfer shoulder. Ann Phys Rehab Med 2012;(1):182–8. https://doi.org/10.1016/j.rehab.2012.07.661.

[7] Langenberg LC, Lima GV, Heitkamp SE, Kemps FLAM, Jones MS, Moreira MAAG, et al. The surfer's shoulder: a systematic review of current literature and potential pathophysiological explanations of chronic shoulder complaints in wave surfers. Sports Med 2021;7(2). https://doi.org/10.1186/s40798-020-00289-0.

[8] Flores-Hernandez C, Eskinazi I, Hoenecke HR, D'Lima DD. Scapulothoracic rhythm affects glenohumeral joint force. J Shoulder Elbow Surg 2019;3(2):77–82. https://doi.org/10.1016/j.jses.2019.03.004.

[9] Hickey D, Solvig V, Cavalheri V, Harrold M, Mckenna L. Scapular dyskinesis increases the risk of future shoulder pain by 43% in asymptomatic athletes: a systematic review and meta-analysis. Br J Sports Med 2017;52(2):1–10. https://doi.org/10.1136/bjsports-2017-097559.

[10] Uhl TL, Kibler WB, Gecewich B, Tripp BL. Evaluation of clinical assessment methods for scapular dyskinesis. Arthroscopy 2009;25(11):1240–8. https://doi.org/10.1016/j.arthro.2009.06.007.
[11] Clarsen B, Bahr R, Haugsboe SH, Munk R, Myklebust G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. Br J Sports Med 2014;48(17):1327–33. https://doi.org/10.1136/bjsports-2014-093702.
[12] Burn MB, McCulloch PC, Lintner DM, Liberman SR, Harris JD. Prevalence of scapular dyskinesis in overhead and non-overhead athletes: a systematic review. Orthop J Sports Med 2016;4(2). https://doi.org/10.1177/2325967115627608.
[13] Ellenbecker TS, Kibler WB, Davies GJ. Reliability of scapular classification in examination of professional baseball players. Clin Orthop 2012;470(6):1540–4. https://doi.org/10.1007/s11999-011-2216-0.
[14] Madsen PH, Bak K, Jensen S, Welter U. Training induces scapular dyskinesis in pain-free competitive swimmers: a reliability and observational study. Clin J Sport Med 2011;21(2):109–13. https://doi.org/10.1097/JSM.0b013e3182041de0.
[15] Maor MB, Ronin T, Kalichman L. Scapular dyskinesis among competitive swimmers. J Bodyw Mov Ther 2017;21(3):633–6. https://doi.org/10.1016/j.jbmt.2016.11.011.
[16] Tate AR, McClure PW, Kareha S, Irwin D, Barbe MF. A clinical method for identifying scapular dyskinesis, part 2: validity. J Athl Train 2009;44(2):165–73. https://doi.org/10.4085/1062-6050-44.2.165.
[17] Welbeck AN, Amilo NR, Le DT, Killelea CM, Kirsch AN, Zarzour RH, et al. Examining the link between thoracic rotation and scapular dyskinesis and shoulder pain amongst college swimmers. Phys Ther Sport 2019;40:78–84. https://doi.org/10.1016/j.ptsp.2019.08.013.
[18] Sciascia AD, Kibler WB. Current views of scapular dyskinesis and its possible clinical relevance. Int J Sports Phys Ther 2022;17(2):117–30. https://doi.org/10.26603/001c.31727.
[19] Nessler JA, Silvas M, Carpenter S, Newcomer SC. Wearing a wetsuit alters upper extremity motion during simulated surfboard paddling. PLoS One 2015;10(11). https://doi.org/10.1371/journal.pone.0142325.
[20] Stergiou N, Decker L. Human movement variability, nonlinear dynamics, and pathology: is there a connection? Hum Mov Sci 2011;30(5):869–88. https://doi.org/10.1016/j.humov.2011.06.002.
[21] Nessler JA, Ponce-Gonzalez JG, Robles-Rodriguez C, Furr H, Warner M, Newcomer SC. Electromyographic analysis of the surf paddling stroke across multiple intensities. J Strength Condit Res 2019;33(4):1102–10. https://doi.org/10.1519/jsc.0000000000003070.
[22] Furness J, Schram B, Cottman-Fields T, Solia B, Secomb J. Profiling shoulder strength in competitive surfers. Sports 2018;6(52). https://doi.org/10.3390/sports6020052.
[23] Madeira M, Nobre P, Costa T, Almeida V, Paulo Sousa J, Pereira AM. Isokinetic profiles of the shoulder internal and external rotators in surfers. Ann Med 2019;51(S1):218. https://doi.org/10.1080/07853890.2018.1560727.
[24] Phadke V, Camargo PR, Ludewig PM. Scapular and rotator cuff muscle activity during arm elevation: a review of normal function and alterations with shoulder impingement. Rev Brasileira Fisioterapia 2009;13(1):1–9. https://doi.org/10.1590/S1413-35552009005000012.
[25] 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):227–38. https://doi.org/10.2519/jospt.2005.35.4.227.
[26] Turgut E, Duzgun I, Baltaci G. Scapular asymmetry in participants with and without shoulder impingement syndrome. Clin Biomech 2016;39:1–8. https://doi.org/10.1016/j.clinbiomech.2016.09.001.
[27] Kibler WB, Ludewig PM, McClure PW, Michener LA, Bak K, Sciascia AD. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the "scapular summit". Br J Sports Med 2013;47(14):877–85. 0.1136/bjsports-2013-092425.
[28] McClure PW, Tate AR, Kareha S, Irwin D, Zlupko E. A clinical method for identifying scapular dyskinesis, part 1: reliability. J Athl Train 2009;44(2):160–4. https://doi.org/10.4085/1062-6050-44.2.160.
[29] Paraskevopoulos E, Papandreou M, Gliatis J. Reliability of assessment methods for scapular dyskinesis in asymptomatic subjects: a systematic review. Acta Orthop Traumatol Turcica 2020;54(5):546–56. https://doi.org/10.5152/j.aott.2020.19088.
[30] Fleiss JL. Measuring nominal scale agreement among many raters. Psychol Bull 1971;76(5):378–82. https://doi.org/10.1037/h0031619.
[31] Hosseinimehr SH, Anbarian M, Norasteh AA, Fardmal J, Khosravi MT. The comparison of scapular upward rotation and scapulohumeral rhythm between dominant and non-dominant shoulder in male overhead athletes and non-athletes. Man Ther 2015;20(6):758–62. https://doi.org/10.1016/j.math.2015.02.010.