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The Relationship Between Preseason Upper Extremity Function, Pain, and Training and Normalized Division III Collegiate Swimming Performance

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Context: Shoulder injuries comprise the largest proportion of swimming injuries, and a large percentage of swimmers participate with pain. Therefore, it is assumed that shoulder pain decreases performance, but researchers have not compared collegiate swimmers' performance with and without pain.

Objectives: (1) To determine if individual swimmers' shoulder pain and function are associated with a change in normalized swimming performance over a season, (2) to determine if differences in normalized swimming performance exist among 3 collegiate teams, and (3) to qualitatively describe and compare each team's training regimes.

Design: Cross-sectional study.

Setting: Swimmers completed preseason (T1) and postseason (T2) surveys including pain ratings and shoulder function using the Kerlan-Jobe Orthopaedic Clinic (KJOC) shoulder and elbow questionnaire. Swimming times were obtained from published meet results. Coaches reported training programs through interviews and tracking logs.

Patients or Other Participants: Fifty-two National Collegiate Athletic Association Division III swimmers from 3 teams.

Main Outcome Measure(s): Stepwise linear regression was used to determine if pain and function related to performance. Team demographics and normalized swimming performance (reduction in time per lap from season beginning to end) were compared with analyses of variance with post hoc tests.

Results: Initial KJOC scores, but not pain, related to individual swimming performance. Differences in team performance were found ($P = .006$), with Team 3 having the greatest reduction in time (1.01 s/lap), a lower percentage of females, a more experienced coach, and a periodization schedule with large increases and decreases in yardage. A main effect ($P = .043$) was found for baseline demographics, with Team 3's swimmers being taller and having longer competitive experience.

Conclusions: The initial KJOC score predicting swimming performance improvement demonstrates the need for athletic trainers to prioritize enhancement of preseason function. Endurance training–induced hypoalgesia and motivation may explain the lack of effect of shoulder pain on performance. Further research is needed to elucidate optimal periodization and dry-land training.

Key Words: shoulder, KJOC, swimming times

Key Points

- Athletic trainers and coaches should collaborate on optimizing preseason Kerlan-Jobe Orthopaedic Clinic scores due to their relationship with improved performance.
- Shoulder pain ratings were not related to swimming performance, which might be explained by motivational factors and endurance training–induced hypoalgesia.
- Team 3, which had a reduction in normalized time per lap of 1.02 seconds, had more male study participants, had swimmers with greater height and more years of competitive swimming experience, had a coach with 3 times the experience of the other coaches, and underwent an in-water training program which had large increases followed by large decreases in training volume.

Competitive swimmers incur a high prevalence of shoulder pain, and authors of an epidemiology study from the National Collegiate Athletic Association (NCAA) found that shoulder injuries comprised the largest proportion of all men's swimming injuries from 2014 to 2019.[1–4] Authors of an earlier study of men's and women's Division I collegiate swimmers found the same injury pattern.[3] A multifactor etiology of shoulder pain has been suggested, including overuse, laxity, shoulder muscle strength ratios, poor posture, reduced pectoralis minor length, and prior history of pain or injury.[1,5] Increased pain and reduced function have been reported in those with greater years of sport participation.[5,6] In addition to pain, authors of ultrasound and magnetic resonance imaging studies have identified shoulder pathology in competitive swimmers, including rotator cuff tendinopathy and tears, acromioclavicular joint pathology, labral pathology, biceps pathology, and arthritis.[2,7] Sein et al have related training volume, including yardage swam per week, to supraspinatus tendinopathy and shoulder pain.[2] One way in which training volume can be monitored is by acute : chronic workload ratios (ACWRs) in which the current workload (acute) is compared with an average prior workload (chronic).[8] Variations in training volume can also affect performance. For example, tapering, which is the reduction in volume before competition, and periodization, which is the purposeful sequencing of different training units, are both used to enhance performance.[9,10] This highlights the potential effect of training strategies on both performance and shoulder pain or pathology.

It has been suggested that musculoskeletal dysfunctions associated with shoulder pain in swimmers may be amenable to rehabilitation or injury prevention programs, and as such, an appropriate dry-land training may mitigate the adverse effects of repetitive shoulder use from their high volume of in-water training.[11,12] For example, Lynch et al reported decreases in forward head and shoulder posture and improved strength of the scapular stabilizers in a group of NCAA Division I swimmers after 8 weeks of a specific exercise program, providing support for the theoretical basis of a training program.[13] However, Tate et al identified aspects of dry-land training that may put swimmers at risk for further injury and found that many dry-land programs failed to address the specific mobility restrictions and weaknesses found in swimmers.[14] In addition, authors of some studies reported that 38% to 44% of shoulder injuries resulted from dry-land training.[3,15]

Although experimentally induced shoulder pain has been shown to reduce voluntary muscle activation, it is not known whether shoulder pain or reductions in preseason shoulder function decrease performance over the course of a season.[16] In addition, authors have not compared the performance of swimmers undergoing varied in-water and dry-land training programs. Therefore, the purpose of this study was threefold: (1) to determine if individual swimmers' shoulder pain and function are associated with a change in normalized swimming performance over a season, (2) to determine if differences in normalized swimming performance exist among 3 collegiate teams, and (3) to qualitatively describe and compare each team's training regimes.

METHODS

The researchers contacted the head coaches of 3 Division III collegiate swimming teams, who agreed to participate in this prospective repeated-measures study. All swim team members viewed a prerecorded explanatory video, and the researchers were available via Zoom (Zoom Video Communications, Inc) to answer questions, as this study occurred during the COVID-19 pandemic, which restricted live visitor access. The first of 2 online surveys was then sent to the coaches, who forwarded it to all their swimmers. Interested swimmers then acknowledged their consent and completed the surveys. This study was approved by Arcadia University Institutional Review Board.

A total of 59 Division III collegiate swimmers aged 18 to 22 completed the first survey, and 52 completed the second survey. Seven participants did not have recorded end-of-season times. At the end-of-season interviews, coaches mentioned that 2 swimmers transferred schools, and 1 swimmer reported illness and was not able to compete. The coaches were not aware of which swimmers were participating in the study, and so the reasons for the remaining 4 swimmers' lack of completion are unknown (Figure 1). Swimmers were excluded from the study if they had less than 2 years' swimming experience to eliminate large-scale performance gains often attained by novice swimmers.

Design

Survey. Swimmers completed Google surveys during the first week of practice in September (T1) and at the end of the season immediately after championships (T2). The T1 survey requested demographic information and each swimmer's anticipated main competitive events. Shoulder pain was rated from 0 to 10 at rest, with normal activities, and with strenuous activities as adapted from the Penn Shoulder Score, and function was assessed using the Kerlan-Jobe Orthopedic Clinic (KJOC) shoulder and elbow questionnaire, which consists of 10 items and has been validated as a measure of upper extremity function in overhead athletes. Scores range from 0 to 100, with lower scores indicating greater shoulder impairment.

Coach Interviews. One of the researchers (L.W.) conducted and recorded semistructured Zoom interviews with

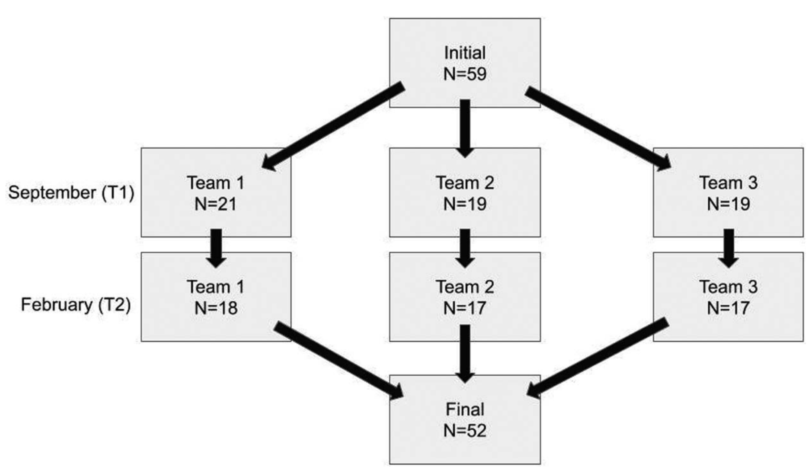

Figure 1. Enrollment and tracking of swimmers from 3 Division III swim teams from the beginning of the season (T1) to the end of the season (T2).

each coach at T1 and T2 and subsequently transcribed each interview. Information was requested about each coach's years of experience and each team's dry-land training program, including the number of dry-land training hours per week and the contents of the program broken down into 8 categories: strength, conditioning, sports-specific, cardiovascular training, weight training, core training, flexibility, and other. Additionally, coaches recorded their teams' weekly in-water average and minimum and maximum training yardage on a Google Sheet. Minimum and maximum in-water training volumes reflect higher training yardages for distance swimmers and lower training yardage for sprinters. For coaches who did not report the average in-water yardage, it was calculated as the average of the maximum and minimum training yardage. The average yardage was used for data plotting.

Performance Times. We obtained individual swimmers' event times from published results on each team's Website. Beginning-of-season times (T1) were recorded for 3 meets of each team's season to allow for identification of times from 2 events, if available. Team 1's season ended a week before Teams 2 and 3; therefore, data collection started a week earlier for Team 1, so all teams had an equal number of weeks to train before the final meet. If a swimmer swam the same event within the first 3 weeks of the season, then the time from the earliest meet was recorded as T1. End-of-season times (T2) were recorded for any events that the swimmer swam during the championship meet that were also swam within the first 3 weeks of the season. Fifty-one swimmers had times for at least 1 event within the first 3 meets of the season and a corresponding time for the same event at championships. A time for 1 swimmer was used from the fourth meet, as that swimmer had no events within the first 3 meets corresponding to events swam at championships. Times for all individual events were included in the study except the 1650-m freestyle event, which is only swam at championships.

In this study, a change in performance (ie, normalized performance) was defined as the difference in time between T1 and T2 divided by the number of laps for the event. For example, if a swimmer swam the 100-m freestyle in 60 seconds at T1 and 56 seconds at T2, the 4-second difference was divided by 4 for each lap in the event for a 1-s/lap improvement in normalized performance over the season. This allowed for comparison of the change in time per lap or swimming velocity between swimmers of different events. If a swimmer had 2 events with times at the beginning and end of the season, his or her change per lap was averaged between the events for the individual swimmer.

Statistical Analysis

A stepwise multiple regression analysis was performed to identify if either pain or function was related to swimming performance. Separate analyses of variance with Tukey post hoc tests were performed to compare demographic data between groups. They were also performed to compare swimming performance among the 3 teams at each of the 2 time points throughout the season. SPSS (version 27; IBM Corp) was used for statistical analysis with an α level of $P = .05$.

RESULTS

Table 1 shows the results of the stepwise multiple regression analysis, demonstrating which variables were associated with normalized individual swimming performance in Division III swimmers. Pain was not associated with normalized individual swimming performance, but the initial KJOC score did relate to normalized individual swimming performance. Table 2 presents self-reported aspects of each team's coaching experience and dry-land training elements. Table 3 reports the baseline team demographic information from each of the 3 Division III swim teams, which was obtained via self-report Google surveys. A significant main effect ($P = .043$) was found for baseline demographics, with Team 3 swimmers having greater height and years of competitive experience. In addition, Team 3 had a lower percentage of females participating versus Teams 1 and 2. Table 4 reports the change in team swimming performance from the beginning of the season (T1) to the end of the season (T2). A significant effect ($P = .006$) was found for swimming performance with post hoc differences in improvement of swimming time per lap found between teams. Team 3's change in swimming time of −1.02 s/lap was greater than Team 2's, and Team 1's performance was also greater than Team 2's.

DISCUSSION

The first purpose of our study was to determine if individual swimmers' shoulder pain and function are associated with a change in normalized swimming performance over a season. The second purpose was to determine if differences in normalized swimming performance exist among 3 collegiate teams. The last purpose was to qualitatively describe and compare each team's training regimes.

Association of Shoulder Pain and Function With Individual Swimming Performance

To investigate the association between shoulder pain and self-reported function with individual swimming performance, swimmers completed the KJOC and reported their pain ratings

Table 1. Stepwise Regression Analysis Associated With Individual Swimming Performance

	Individual Swimming Performance					
Predictor	R^2	Unstandardized *B*	SE	Standardized β	*t*	Sig
Step 1	0.12					
KJOC total T1	NA	−0.01	<0.01	−0.34	−2.07	0.05[a]
Constant	NA	−0.37	0.25	NA	−1.49	0.15

Abbreviations: KJOC, Kerlan-Jobe Orthopaedic Clinic; NA, not available; SE, standard error; T1, preseason.
[a] Significant relationship with individual swimming performance.

Table 2. Coaches' Self-Reported Experience, Dry-Land Training Elements, and Parameters

Training Parameter	Team 1	Team 2	Team 3
Coaching experience	12 y	12 y	36 y
Dry land frequency	2–3 h × 2–3 d/wk	4 h × 2 d/wk; 3 d/wk on off weeks	3.5 h × 3 d/wk
Dry land specific warm-up	Did not report or perform	Did not report or perform	Dynamics 1 h before practice; each drill × 20 yards; high knees, butt kicks, shuffles, carioca or grapevine, and floor sweeps
Prehab	Everyday; rotator cuff muscles, miniband exercises	2 d/wk; shoulder or upper back exercises	Unknown frequency; included overhead squats, latissimus pull downs, overhead weighted ball slams, kettlebell swings, and hang snatches
Dry land elements			
Strengthening	Yes	Yes	Yes; specifically for middle and lower trapezius
Sport-specific	Yes	Yes	Yes
Cardiovascular training	No	Yes	No
Weight training	Yes	Yes	Yes
Core training	Yes	Yes	Yes
Flexibility	No	Yes	Individual basis; specifically pectoral stretches
Other	No	Spin, yoga	Plyometrics

at T1 and T2. The authors hypothesized that pain would negatively influence swimming performance due to the inhibitory effect of pain on shoulder muscle activation, but the results did not support our hypothesis.[16] One potential explanation for this may be endurance sport-related hypoalgesia. Naugle et al found that acute aerobic exercise had a moderate to large mean effect on reducing pain perception.[17] It is proposed that this may be due to the release of peripheral and central β-endorphins associated with altered pain sensitivity. Therefore, high-level athletes who participate in sports with long durations of physically intense activity have an increased ability to tolerate pain.[17]

Motivational aspects of competition also exist, such as the influences of resilience, mental toughness, coping, and grit that may affect performance.[18] Grit has been linked to conscientiousness, and high levels of conscientiousness have been associated with diminished experiences of pain.[18] Many collegiate athletes compete for the love of their sport and for their personal and team success, so the motivation to continue to push oneself through pain to achieve may help to explain the finding that shoulder pain did not negatively affect normalized competitive performance.

Our findings suggest that beginning-of-season shoulder function, as measured by the T1 KJOC score, was related to individual normalized swimming performance (Table 3). To our knowledge, with this study, we are the first to relate the KJOC score to specific performance metrics. These results help to provide support that shoulder function has a direct effect on performance and therefore should be a focus in the athlete's overall training program. Although not directly related, these findings are similar to those of research in baseball players and other overhead athletes.

Table 3. Baseline Team Demographics Information From Division III Swim Teams Obtained via Self-Report on a Google Survey

	Demographics		
	Team 1	Team 2	Team 3
Females, No. (%)	13 (61.9%)	11 (57.9%)	7 (36.8%)
Males, No. (%)	8 (38.1%)	8 (42.1%)	12 (63.2%)
Age, (y), mean ± SD	18.72 ± 0.90	19.18 ± 1.24	19.50 ± 1.21
P value (versus Team 1)	NA	.46	.12
P value (versus Team 2)	NA	NA	.69
Height, (cm), mean ± SD	170.18 ± 5.31	176.91 ± 7.24	177.01 ± 7.52
P value (versus Team 1)	NA	.01[a]	.01[b]
P value (versus Team 2)	NA	NA	>.99
Weight, (kg), mean ± SD	67.55 ± 8.52	73.79 ± 10.08	74.17 ± 11.42
P value (versus Team 1)	NA	.17	.14
P value (versus Team 2)	NA	NA	.99
Competing, (y), mean ± SD	9.67 ± 3.07	11.65 ± 3.33	12.69 ± 2.98
P value (versus Team 1)	NA	.16	.02[b]
P value (versus Team 2)	NA	NA	.61
Initial KJOC, mean ± SD	83.18 ± 21.65	76.00 ± 21.10	83.34 ± 22.72
P value (versus Team 1)	NA	.60	.99
P value (versus Team 2)	NA	NA	.52

Abbreviations: KJOC, Kerlan-Jobe Orthopaedic Clinic; NA, not available.
[a] Significant difference from Team 1 to Team 2.
[b] Significant difference from Team 1 to Team 3.

Table 4. Change in Team Normalized Swimming Performance From the Beginning of the Competitive Season (T1) to the End of the Competitive Season (T2)

	Team Performance		
	Average Δ/lap (s), mean ± SD	*P* Value (versus Team 1)	*P* Value (versus Team 2)
Team 1	−0.92 ± 0.52	NA	.04[a]
Team 2	−0.57 ± 0.36	NA	NA
Team 3	−1.02 ± 0.31	.75	.01[b]

Abbreviation: NA, not available.
[a] Significant difference between Team 1 and Team 2.
[b] Significant difference between Team 2 and Team 3.

Kraeutler et al found that Major League Baseball players had higher KJOC scores than their Minor League counterparts.[19] Major League Baseball requires a higher level of performance than Minor League Baseball, so higher KJOC scores were associated with better performance. Additionally, O'Brien et al used KJOC scores to record functional performance after ulnar collateral ligament repair in overhead athletes, which included baseball and javelin players.[20] They found that the athletes who were able to return to their previous level of function had greater KJOC scores than those athletes who were unable to return to sport. These findings are consistent with our findings of higher KJOC scores being associated with greater normalized swimming performance; therefore, swimmers with higher levels of shoulder function in the beginning of the season may have had greater potential for improved normalized performance.

Normalized Performance Comparison Among 3 Division III Teams

A novel method was used in this study to compare normalized performance among 3 collegiate Division III swim teams by comparing swimmers' lap normalized times at the beginning and end of the season. Teams 1 and 3 had significantly greater improvements in speed from the beginning to the end of the season than Team 2, with Team 3 having an average normalized reduction in time of 1.02 s/lap (Table 2). Given that a difference in normalized performance across the teams was found, the baseline demographics and both the in-water and dry-land training regimes of all 3 teams were investigated.

Baseline Demographics. Baseline demographic comparison revealed that Team 3's mean height was greater ($P = .013$) than Teams 1 and 2 (Table 1). Previous researchers have found that taller swimmers have an increased probability of swimming faster, which could potentially contribute to the improved swimming performance observed in Team 3.[21] In the literature, faster swimmers have been found to be taller and have a wider arm span and larger body dimensions, which could create a greater propulsive force from both the arm pull and the leg kick. In addition, Team 3 had a lower percentage of females versus males.[22] Sex-related differences in performance have been found for freestyle and breaststroke; however, it is not known if height or sex differences or both may have contributed to relative team performance improvements.[23,24]

The swimmers of Team 3 also had more years of swimming experience ($P = .019$; Table 1). The authors thought that this would lead to Team 3 swimmers having less improvement in swimming times. Authors of studies have shown that increased years of swimming are associated with higher pain levels and supraspinatus tendinopathy.[1,2,5] We hypothesized that this would reduce swimming performance. However, Team 3 had the most years of experience and best performance. Interestingly, authors of research on open-water elite swimmers found that faster swimming is associated with both increasing age and more experience.[25] They felt that experience would improve swimmers' tactical decisions in their open-water, longer-duration race, so it is unclear if the increased experience would be advantageous for in-pool competitions.[25] In addition to Team 3's swimmers having more years of swimming experience, the coach of Team 3 had 3 times the amount of coaching experience compared with the other coaches. Further research is needed to explore the role of swimming and coaching experience on performance.

Qualitative Description of Team Training Regimes

In-Water Training. The in-water training yardages of the 3 teams were plotted from the records provided by each coach. Our description specifically focused on reporting the periodization (Figure 2) and ACWRs (Figure 3) among the teams.

Periodization. Hellard et al have described periodization as the deliberate structure and sequencing of training units to maximize performance and minimize injury.[10] Annual or seasonal training plans are divided into smaller, distinct phases often conceptualized as temporal cycles at intervals preceding competition. Mesocycles are time blocks spanning 2 to 8 weeks.[26] Within these cycles, coaches and trainers modulate training variables such as weekly yardage to try to achieve desired performance results. In their analysis of periodization or the changes in training load of elite swimmers in the final 11 weeks preceding competition, Hellard et al defined 4 mesocycles: the taper 1 to 2 weeks prior, the short term 3 to 5 weeks prior, the medium term 6 to 8 weeks prior, and the long term 9 to 11 weeks prior.[10] They found that increases in training load in weeks 3 to 11 before competition generally correlated with improved swimming performance, with the greatest positive effect seen with training load increases in the 6 to 8 weeks before competition.[10] Conversely, increases in training load in the final 2 weeks before competition negatively affected swimming performance.[10]

Further, Hellard et al found that a 10% increase in training load in weeks 6 to 11 before competition for sprinters and in weeks 3 to 11 for mid-distance swimmers yielded faster performance, and other investigators have found that only substantial volume decreases between 60% and 90% of weekly training load can correlate with a 3% improvement in swimming performance.[10,27] They hypothesized that high-volume endurance training reduced muscular power by causing fatigue, inhibiting neuromuscular properties, or both, whereas a sufficient decrease in training load, known as a taper, would restore power while maintaining the metabolic benefits from the endurance training.[27]

The reported training plots revealed that Team 3's periodization schedule in the last 11 weeks before championships included large increases in weekly swim yardage in the long-term (weeks 9 to 11 before championships) and

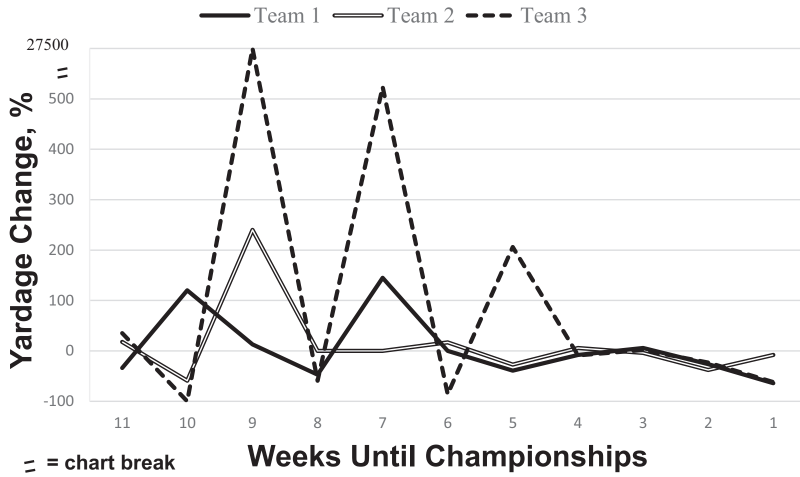

Figure 2. Periodization schedule: week-to-week percentage change in swim yardage of 3 Division III teams across the 11 weeks before championships.

medium-term (weeks 6 to 8 before championships) mesocycles. Team 3 also decreased their weekly yardage between 60% and 90% in 3 separate weeks. Based on these metrics, Team 3's periodization schedules are consistent with research in which authors demonstrated that each 10% increase in total training load in medium-term and long-term mesocycles is associated with faster swim times in sprint events.[10] Additionally, Team 3's periodization schedule, with 3 separate 60% to 90% reductions in total training load in the last 11 weeks of the season, correlates with research in which authors demonstrated that decreases of total training load within this range are associated with 3% improvements in swimming performance.[27]

Acute : Chronic Workload Ratios. Acute : chronic workload ratios (ACWRs) represent a unit by which to measure fitness against fatigue. In other words, current workload (acute) is compared with the average prior workload (chronic). We have plotted the ACWRs using the current week's average training yardage divided by the average of the prior 4 weeks' training yardage. Team 3 had the highest peak ACWRs and large fluctuations in their ACWRs. It is not known if the very high peak followed by low dip in ACWRs may have allowed for recovery to enhance performance, as authors of studies have not investigated the effect of ACWRs fluctuations on swimming performance. The plots of all the teams show a taper in the final 3 weeks before championships. An end-of-season taper in collegiate swimmers has been shown to increase arm mechanical power and improve swim performance.[23,24]

Dry-Land Training. All 3 teams reported including prehabilitation training. Prehabilitation is defined as a proactive strengthening program to prevent injury. Due to the high occurrence of overuse injuries in swimming, incorporating prehabilitation into training regimes might be effective. Team 3 reported avoiding overhead lifting exercises in their prehabilitation programming, which could potentially overload the supraspinatus, which is at risk for tendinopathy due to high-volume swimming training, but Team 3's training documents do include overhead lifting exercises such as overhead squats, overhead weighted ball slams, and kettlebell swings (Table 4).[2] Although Team 2 initially reported that prehabilitation was included in their dry-land training, they

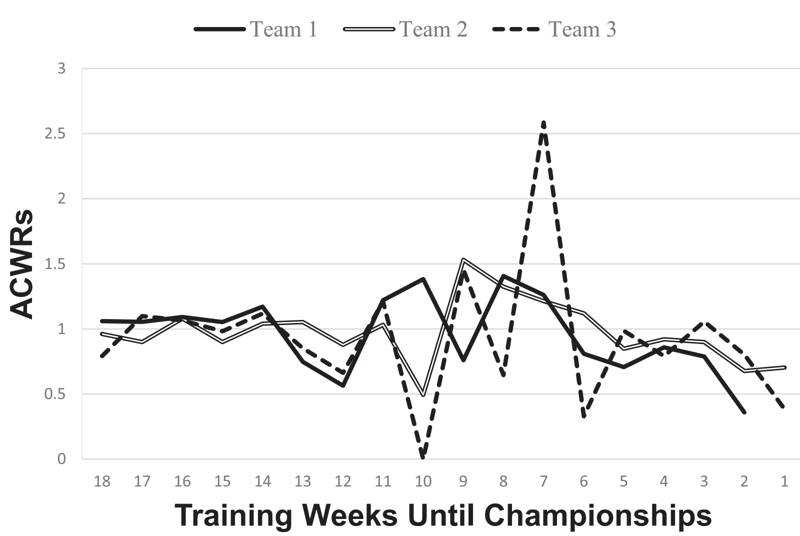

Figure 3. Acute : chronic workload ratios (ACWRs) across the swim season.

later stated they had difficulty incorporating it into their programming due to poor attendance, noting that only 6 to 8 swimmers participated regularly. Therefore, specific comparison of prehabilitation programs was not possible.

Team 3 was the only team that included lower extremity plyometrics in their dry-land training regime (Table 4). This may have facilitated a more efficient push-off from the starting block or a more forceful push-off from the wall during flip turns, which could potentially reduce the number of strokes per lap and therefore reduce the load on swimmers' shoulders. It has been found that the inclusion of plyometric training routines can have a positive effect on swim start performance.[28] The time spent on starts and turns can contribute to a decline in overall time during a race, so having an advantage of getting off the blocks and the walls more quickly could contribute to overall improved performance.

Team 3 also included dry-land training elements that specifically address typical muscle weaknesses and flexibility deficits found in competitive swimmers, which have been associated with pain and swimming-related disability.[1] These specific weaknesses include the musculature of the core and middle trapezius and reduced length of the pectoralis minor.[1] Team 3 reported including exercises targeting both the core and lower and middle trapezius muscles in their dry-land training regimes. Increased endurance of the posterior shoulder muscles has been suggested to have a protective effect on swimmers' shoulders by counteracting the increased strength and endurance of the internal rotators over the external rotators, which occur from the demands of freestyle stroke mechanics.[29,30] Team 3 also included pectoralis muscle stretches (Table 4). Borstad and Ludewig found that reduced length of the pectoralis minor may alter scapular mechanics, thereby potentially contributing to compression of the subacromial structures.[31] Pectoral stretching and middle and lower trapezius strengthening may therefore help to increase pectoral length and stabilize the scapula in an optimal position to reduce injury risk and favorably affect stroke mechanics.

Limitations

The study had several limitations. Our periodization data were solely based on yardage values. Authors of previous studies included blood lactate concentrations to stratify training intensity levels.[10] Additionally, we were only able to collect team yardage data using means reported by each coach, not individual yardage swam, which prevented individual data analysis. In addition, we were unable to collect individual data for missed training days; however, 1 coach reported that a significant number of swimmers contracted COVID-19 before championships, which may have affected their training, taper, and overall performance.

CONCLUSIONS

In this study, we present a novel method for comparing normalized swimming performance among teams, and we are the first, to the authors' knowledge, to investigate both in-water and dry-land training variables. With respect to our findings, coaches and athletic trainers should focus on optimizing shoulder function before the competition season, as self-reported preseason function was associated with end-of-season normalized performance. Pain was not associated with normalized swimming performance, so factors such as motivation, grit, and endurance training–induced hypoalgesia may play a role in mitigating a potential pain-induced reduction in muscle activation during swimming competition. Because this study occurred during a pandemic in which the health of the swimmers was not assessed and baseline differences in sex, height, swimming experience, and coaching experience were found, one cannot conclude that the differences in normalized performance found among the teams were due to their pool or land-based training. However, Team 3's periodization schedule and dry-land training components are supported by prior research. Further research is needed to elucidate optimal periodization, ACWRs, and dry-land training regimes, as well as the role of anthropomorphic variables, sex, and coaching experience in swimming performance.

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