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Workload and Noncontact Musculoskeletal Injury in Collegiate Swimmers: A Prospective Cohort Study

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Context: Swimmers are known for experiencing high training loads and a high incidence of overuse injuries, but few researchers have investigated the relationship between the two at the collegiate level.

Objective: To determine the association between workload and noncontact musculoskeletal injury in collegiate swimmers.

Design: Prospective cohort study.

Setting: College natatorium.

Patients or Other Participants: A total of 37 National Collegiate Athletic Association Division III swimmers, 26 uninjured (age = 19 years [interquartile range = 3 years], height = 175 ± 11 cm, mass = 70.2 ± 10 kg) and 11 injured (age = 19 years [interquartile range = 3 years], height = 173 ± 9 cm, mass = 69.4 ± 13.5 kg) individuals.

Main Outcome Measure(s): Logistic regression using generalized estimating equations was conducted to calculate odds ratios (ORs) with 95% CIs for injury relative to high workloads and high acute:chronic workload ratio (ACWRs). Injury rates for several ranges of workloads and ACWRs were also calculated.

Results: A total of 11 participants (29.7%) sustained 12 injuries, with 7 injuries occurring during the participants' winter training trip. Injury was associated with high acute workloads (OR = 27.1; 95% CI = 8.2, 89.8) and high ACWRs (OR = 25.1; 95% CI = 7.7, 81.4) but not high chronic (OR = 2.6; 95% CI = 0.3, 20.0) or overall (OR = 1.00; 95% CI = 0.99, 1.01) workloads. High acute workloads (>37.2 km/wk) and ACWRs (>1.56) increased the injury rate from ≤1% to 15% and 14%, respectively, compared with all lower acute workloads and ACWRs.

Conclusions: Collegiate swimmers tolerated high workloads spread out during the season. However, caution should be used when prescribing high acute workloads and high ACWRs (eg, winter training trip) because of the increased odds of injury.

Key Words: training monitoring, acute workload, chronic workload

Key Points

- For their student-athletes, collegiate swim coaches may prescribe high overall workloads spread out over the season without risking increased odds of injury.
- However, coaches should be cautious in prescribing high acute workloads (ie, weekly workloads) and high acute:chronic workload ratios (ie, the ratio of the acute workload to the current month's chronic workload).
- Given the concentrated number of injuries during the winter training trip, coaches should carefully weigh the performance benefits of these trips against the increased odds of injury.

Competitive swimmers are well known for experiencing both high workloads[1–3] and a high incidence of overuse injuries.[3,4] These overuse injuries may reflect errors in the workload prescription (eg, sudden increases in training volume or intensity).[5] However, in reviews of injury risk factors in swimmers, researchers[6,7] have drawn mixed conclusions on the relationship between workload and injury. In a recent systematic review,[6] the investigators found moderate-quality evidence for high workloads increasing the injury risk in adolescent swimmers but low-quality evidence in older and younger swimmers. The lack of high-quality evidence for college-aged swimmers (age range = 18–22 years) was unexpected, given that they undertake the highest workloads.[6] Only 2 of the 12 studies in the systematic review[6] were prospective.[8,9] In both prospective studies, the authors observed no association between workload and injury, although 1 study[8] was limited by 85% missing data. Additional prospective evidence is needed, especially in collegiate swimmers.

An emerging method for assessing the relationship between workload and injury is the acute:chronic workload ratio (ACWR).[10] The ACWR is typically calculated as the workload during the most recent week (acute) divided by the workload during the most recent 4 weeks (chronic). This metric is thought to be more relevant to injury than acute or chronic workload alone.[10] High ACWRs have been associated with injury in several sports (eg, cricket, rugby, and Australian football).[10] The current evidence suggests a "danger zone" for increased injury risk when the ACWR exceeds 1.5 (ie, acute workload 50% higher than the chronic workload).[10] Although no researchers have measured the ACWR in swimmers, Sein et al[3] did provide a danger zone for average weekly workload in their cross-sectional study of elite swimmers aged 13 to 25 years. Swimming >35 km/wk increased the risk of supraspinatus tendinopathy 4-fold compared with all lower workloads.[3] A metric such as this for the ACWR in swimming could help coaches plan training.[11] In fact, multiple authors[4,6,11] have called for an ACWR-type analysis in swimmers.

The purpose of our prospective surveillance study was to determine the extent to which workload was associated with noncontact musculoskeletal injury in collegiate swimmers. We hypothesized that higher overall workloads (kilometers swum throughout the season) would be associated with increased odds of noncontact musculoskeletal injury. We also hypothesized that high ACWRs would be more strongly associated with odds of noncontact musculoskeletal injury than would high acute or chronic workloads alone.

METHODS

Participants

For this prospective cohort study, we recruited participants at a preseason team meeting of 1 National Collegiate Athletic Association (NCAA) Division III swim team. Athletes were eligible for inclusion if they were at least 18 years old and medically cleared to participate in sport. Volunteers who were non-English speakers and were unable to provide consent were excluded. A sample-size calculation for this study was based on the coach-reported injury incidence from the previous season (27%) and the need for a minimum of 10 injuries for logistic regression.[12] This calculation suggested a minimum of 37 participants were required. Forty-one student-athletes provided written informed consent to participate during their 2018–2019 season and 37 completed the season (Table 1). This study, which the Drexel University Institutional Review Board approved, was part of a larger study in which intrinsic risk factors for injury were also examined.

Procedures

The swim coach provided practice attendance, team training, and competition logs throughout the season. At the beginning of the season and during breaks in mandatory training (eg, Thanksgiving break, winter break), participants self-reported their preseason and self-directed workloads, respectively, via the Research Electronic Data Capture Web application (REDCap). Participants who did not respond to any questionnaire received 2 follow-up email reminders. The return rates for preseason and in-season REDCap workload questionnaires were 100% and 95.5%, respectively, resulting in 5 (0.6%) athlete-weeks of imputed data using team averages. Most training took place in a 25-yd (22.5-m) pool. We converted workloads in yards to kilometers. Our preliminary work verified the coach-reported workloads, with student-athletes completing an average of 97% ± 3% (range = 89%–103%) of the workloads indicated on the logs.

Table 1. Participants' Characteristics

Variable	Student-Athletes: Uninjured (n = 26)	Student-Athletes: Injured (n = 11)	*P* Value
No.			
Sex			.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 swum, mo/y	10 (3)	10 (4)	.93[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.

We defined *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. This definition is similar to that of *interfering pain* in a previous study[8] but has a concrete threshold for interference of 50%. We chose this definition based on evidence that high-volume swimmers had high pain thresholds,[13] and swimmers tended to continue training despite pain.[2] As a result, only about 3 in 10 injuries caused time loss in swimmers.[4] Thus, the 50% threshold included pain that did not result in complete time loss but still substantially interfered with training. Along with the practice attendance and training logs, the swim coach completed weekly injury reports. When the coach reported that a student-athlete had sustained an injury, that individual received a REDCap questionnaire in which he or she verified the injury, selected the mechanism (contact, noncontact, or overuse), described it in detail, and indicated the number of days affected (see Supplemental Figure, available online at http://dx.doi.org/10.4085/1062-6050-0135.21.S1). An injury episode ended when the swimmer returned to full sport participation. At the midpoint and end of the season, participants also described (via REDCap) any injuries they had not previously reported. They returned 93.2% of these questionnaires. Although using electronic medical records is the norm for NCAA injury surveillance,[4] the college's athletic trainer discouraged querying these records because of the potential for underreporting. For sports with predominantly overuse injury mechanisms, the use of periodic self-report questionnaires has been encouraged.[14]

Data Analysis

We calculated weekly workloads (Monday through Sunday) for each participant based on practice attendance and team training or competition logs. We categorized workload in 4 ways: (1) overall workload throughout the season, (2) acute workload, (3) chronic workload, and (4) ACWR. *Overall workload* was the number of kilometers

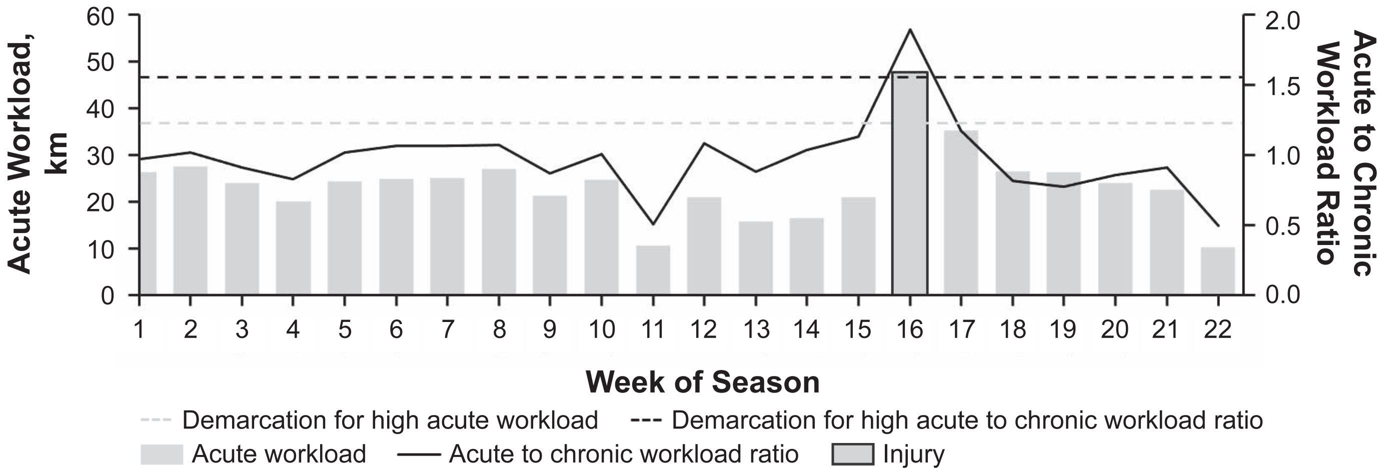

Figure 1. A sample participant's acute workload and acute:chronic workload ratio (ACWR) over the season. This participant sustained a noncontact musculoskeletal injury during the winter training trip (week 16), which coincided with both a high acute workload and a high ACWR, as indicated by the dashed gray and black lines, respectively.

swum over the entire season.[15] *Acute workload* for each week was the number of kilometers swum that week. *Chronic workload* for each week was the average kilometers swum per week over that week and the preceding 3 weeks. The *ACWR* for each week was the quotient of the acute workload and chronic workload.[10] During the first 3 weeks of the season, self-reported preseason workloads factored into the chronic workload and ACWR calculations. We calculated all workloads using Excel (version 16; Microsoft Corp).

Statistical Analysis

The Shapiro-Wilk test and visual inspection of histograms were performed to determine the normality of all data. We used mean ± SD to describe normally distributed data and median (interquartile range [IQR]) to describe nonnormally distributed data. We conducted independent-samples *t* tests to assess differences in descriptive data between injured and uninjured student-athletes except for age and months per year swum (Mann-Whitney *U* tests) and sex and training groups (Fisher exact test).

For the first hypothesis, we used logistic regression to assess the association between the overall workload throughout the season (continuous independent variable) and injury (binary dependent variable). For the second hypothesis, we pooled the data for each of the other 3 workload categorizations (acute workload, chronic workload, and ACWR) for all athlete-weeks of training. We then dichotomized each workload categorization into *high* or *typical*. Because the pooled workload data were not normally distributed, outliers (third quartile + [1.5 × IQR]) signified high workloads and ACWRs. We denoted all other workloads and ACWRs as typical. We calculated 3 logistic regression models (1 for each workload categorization) using generalized estimating equations to assess the association between workload (the dichotomized independent variable) and injury during each athlete-week (the binary dependent variable). The generalized estimating equations accounted for repeated measures. Logistic regression provided odds ratios (ORs) with 95% CIs. Finally, the injury rate for a given range of acute workloads and ACWRs represented the number of injuries that occurred within that range divided by the total number of athlete-weeks in that range. The α level was set at .05. We completed all statistical analyses using SPSS (version 24; IBM Corp).

RESULTS

The 2018–2019 season spanned 21 or 22 weeks, depending on whether the swimmer qualified for the end-of-season championship meet. Competitions began in week 5. Final examinations and winter break interrupted mandatory team practice from weeks 12 to 15. After returning from winter break in week 16, the team went on a trip for 10 days of high-volume training. Before midseason, 4 student-athletes quit the team (reasons unknown), leaving 37 participants. Data from the 37 student-athletes who completed the season yielded a total of 809 athlete-weeks.

Of the 37 participants, 11 (29.7%) sustained 12 injuries. No differences existed in characteristics, training groups, months per year swum, or swimming experience between the uninjured and injured student-athletes (Table 1). Eight injuries were to the shoulder, 3 were to the back or sacroiliac joint, and 1 was to the knee. Participants described the mechanism of 11 injuries as *overuse* and 1 as *overstretching*. Ten injuries were incurred in the water; 2 were incurred on dry land. Participation time altered or lost ranged from 1 day to 2 weeks, with a median (IQR) of 2 (10) days. Nine of the 12 injuries affected participation for ≤4 days. One injury occurred in each of weeks 1, 3, 4, 5, and 18. Seven injuries (6 shoulder and 1 back, all self-reported overuse mechanisms) occurred in week 16.

A sample participant's workload throughout the season is shown in Figure 1. Across participants, the median (IQR) overall workload throughout the entire season was 532 (65) km, which corresponded to a weekly workload of 24.2 (3.4) km. No association existed between overall workload and injury (OR = 1.00; 95% CI = 0.99, 1.01; Figure 2). The demarcations for high acute and chronic workloads and ACWR were 37.2 km/wk and 1.56, respectively. Injury was associated with both a high acute workload and a high ACWR but not a high chronic workload (Table 2, Figure 3). The number and percentage of high workload and high

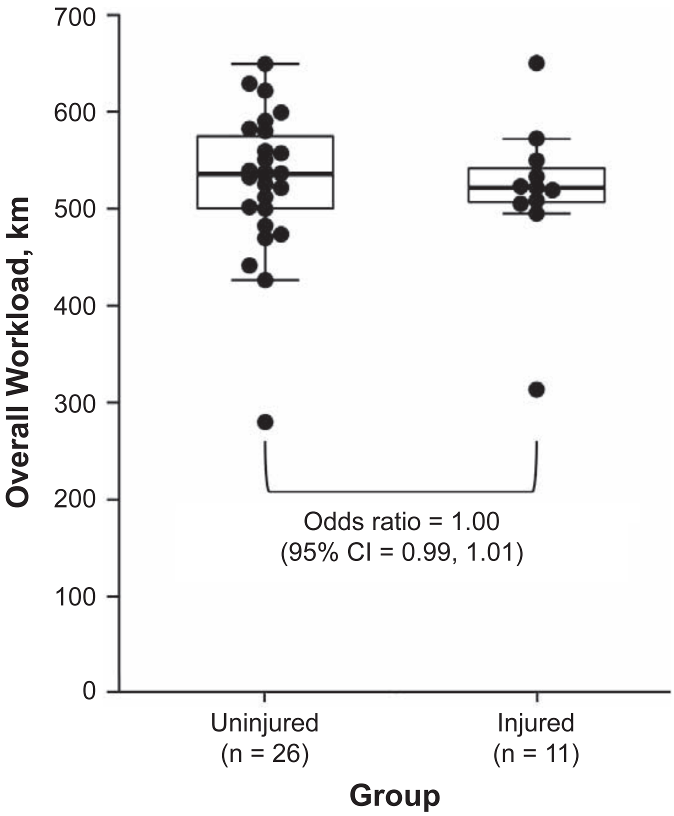

Figure 2. Dot-and-box plots of overall workload (km) over the season for student-athletes who did or did not sustain an injury. No association was observed between overall workload and injury.

ACWR athlete-weeks ranged from 28 (3.5%) to 49 (6.1%; Table 2). Of the 49 high ACWR athlete-weeks and 46 high acute workload athlete-weeks, 32 involved both a high ACWR and a high acute workload. Most high acute workload athlete-weeks (n = 35/46; 76.1%) and high ACWR athlete-weeks (n = 31/49; 63.3%) coincided with the winter training trip (week 16). All 7 of the injuries during week 16 occurred in the presence of a high acute workload and high ACWR. The injury rate was $\leq$1% for typical acute workloads and ACWRs, 15% for high acute workloads, and 14% for high ACWRs (Figure 4).

DISCUSSION

The purpose of our study was to prospectively determine the association between workload and noncontact musculoskeletal injury in collegiate swimmers. The data did not support our first hypothesis: we found no association between overall workload and injury. Our second hypothesis was partially supported. We found that a high ACWR was strongly associated with injury, whereas a high chronic workload was not. Contrary to our hypothesis, a high acute workload was also associated with injury.

Table 2. Association Between Workload Categorizations and Injury

Workload Categorization	Demarcation for High Workload or ACWR	No. of High Workload or ACWR Athlete-Weeks (% of Total)	Odds Ratio (95% CI)
Acute workload	37.2 km/wk	46 (5.7)	27.1 (8.2, 89.8)[a]
ACWR	1.56	49 (6.1)	25.1 (7.7, 81.4)[a]
Chronic workload	37.2 km/wk	28 (3.5)	2.6 (0.3, 20.0)

Abbreviation: ACWR, acute:chronic workload ratio.

[a] $P < .05$.

Overall Workload and Injury

The lack of association between overall workload and injury was consistent with that reported in a previous study[16] of collegiate swimmers. Most researchers who examined college-aged swimmers along with younger and older swimmers also found no relationship between overall workload and injury.[8,9,16–20] The authors of only 2 studies[3,15] that included college-aged swimmers along with other age groups provided evidence for an association between high overall workloads and injury. The contrasting findings from those 2 studies could be due to differences in age ranges and injury definitions.[6] The age ranges reported by Sein et al[3] and Ristolainen et al[15] were 13 to 25 and 15 to 35 years, respectively. In a recent systematic review, Feijen et al[6] suggested that adolescent swimmers may be at high risk of load-related injuries because they have not reached full musculoskeletal and psychosocial maturity. Compared with youth swimmers, athletes who choose to continue swimming in college may be better able to withstand the rigors of high workloads (the "healthy athlete effect").[21] Meanwhile, 1 investigation[22] of masters swimmers (age >23 years) showed that those with shoulder pain had higher workloads than did those without shoulder pain. In addition, whereas we studied interfering pain anywhere in the body, Sein et al[3] studied shoulder pain only and included all severities.

Acute Workload, Chronic Workload, and ACWR and Injury

We observed that high ACWR was no more strongly associated with injury than was high acute workload alone. Although earlier research[23,24] supported the ACWR model of Gabbett,[10] our data did not. Injuries tended to occur as often during weeks with high acute workloads as during weeks with high ACWRs. These results are consistent with a recent analysis[25] of data from 34 elite footballers in which the authors noted that ACWR was no more strongly associated with injury than was acute workload alone or even acute workload scaled by a random chronic workload. In our study, considerable overlap (>65%) existed between high ACWR weeks and high acute-workload weeks. Our findings could be attributed to the nature of this team's training program, which had small week-to-week fluctuations, except for the training trip in week 16. Another possible explanation for the lower-than-expected association between ACWR and injury could be self-report and recall biases. Two injuries occurred during the first 3 weeks of the season, during which time the participants' self-reported preseason workloads factored into calculations for the ACWR. Overestimation of preseason workloads could have resulted in underestimation of ACWRs.

Previous researchers[11] have expressed concerns about an elevated load-related injury risk during winter training trips. We are the first, to our knowledge, to corroborate these concerns with workload surveillance. Seven of the

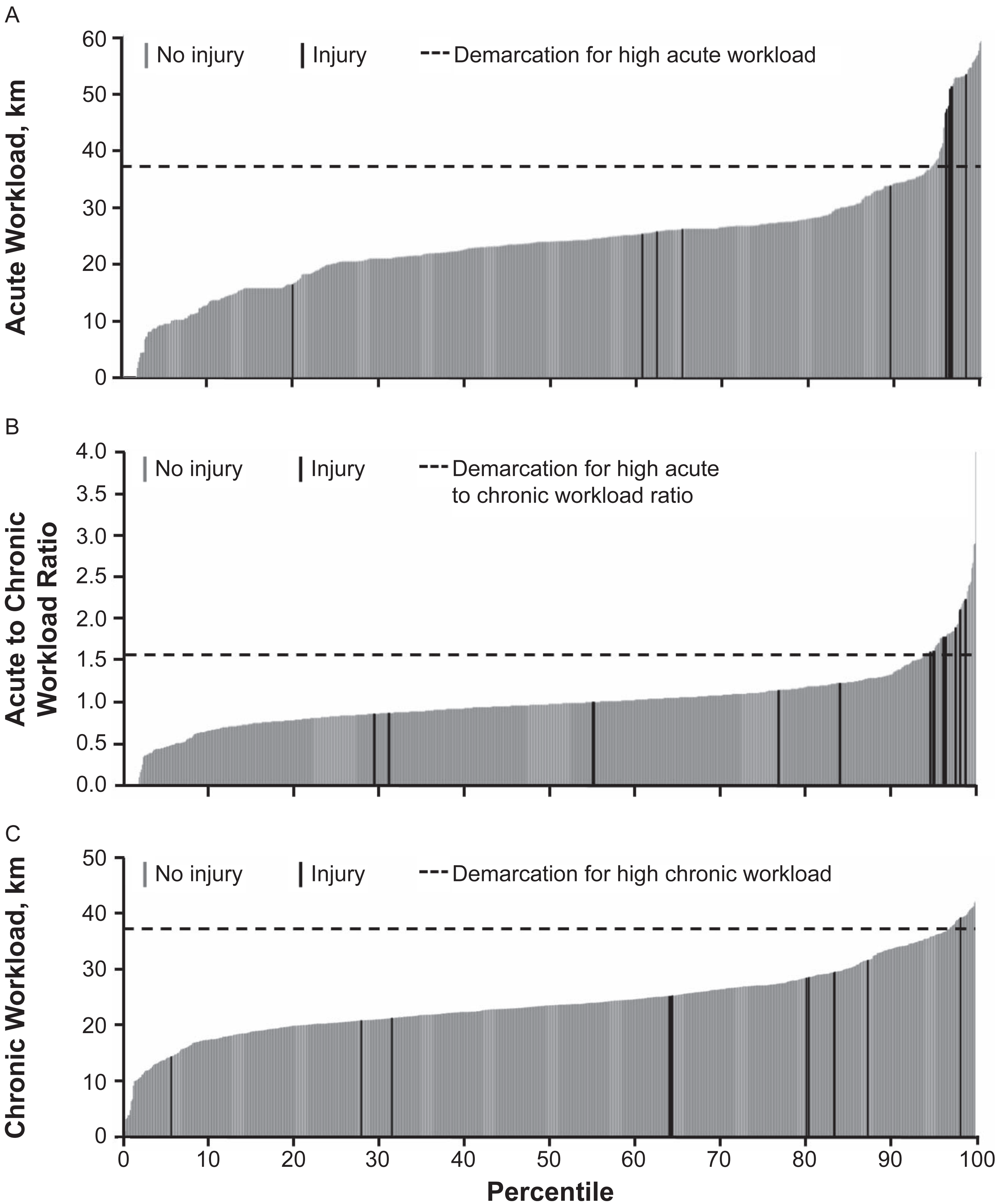

Figure 3. Distribution of (A) acute workloads, (B) acute:chronic workload ratios (ACWR), and (C) chronic workloads for all 809 athlete-weeks during the season, ordered from smallest to largest. Gray vertical lines denote weeks with no injury; black vertical lines denote weeks in which an injury occurred. Horizontal dashed lines indicate the demarcation lines for high workloads and ACWR. Injuries clustered toward the high acute workloads and ACWRs but not the high chronic workloads.

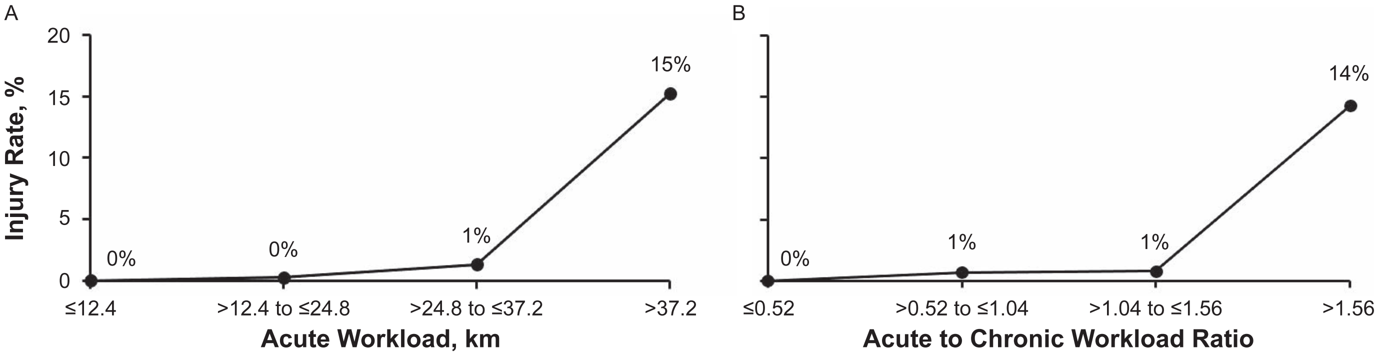

Figure 4. Compared with lower ranges of (A) acute workloads and (B) acute:chronic workload ratios (ACWRs), injury rates during the season increased by an order of magnitude with acute workloads >37.2 km/wk and ACWRs >1.56 (from ≤1% for all lower ranges to 15% and 14% for the high acute workloads and high ACWRs, respectively).

12 injuries in this study occurred during the winter training trip. Swimming tradition dictates that the purpose of the training trip is to expose the student-athletes to high acute workloads.[11] In fact, it is common practice to plan the highest workloads of the season for 6 weeks before the end-of-season competition.[26] Based on supercompensation theory, these workloads are believed to facilitate enhanced performance after tapering for the end-of-season competition.[1] Fittingly, 35 (94.6%) of 37 student-athletes encountered a high acute workload (>37.2 km/wk) during the training trip, and 31 (83.8%) student-athletes encountered a high ACWR (>1.56). Five of the 7 injuries during the training trip affected ≤4 training days. However, the potential long-term effects of these injuries cannot be determined from these data. Regardless, these results raise concerns about whether the performance benefits of a traditional training trip outweigh the increased injury odds.

Because our workload data were not normally distributed, we demarcated high workloads and ACWR via outliers. A *high ACWR* was >1.56, which aligns with the danger zone of ≥1.5 that Gabbett[10] proposed. A *high acute workload* was >37.2 km/wk; this value is similar to that reported by Sein et al[3] (35 km/wk) for an increased risk of supraspinatus tendinopathy. However, their metric corresponded with the average weekly workload (akin to our overall workload) and not acute workload. Workload classifications based on SDs above the mean workload or ACWR have been used previously.[23] Had we used 1 SD above the mean, our demarcations would have been lower: 33.4 km for high acute workloads, 30.5 km for high chronic workloads, and 1.39 for ACWRs. These values would have reduced the associations with injury by classifying more athlete-weeks as high workload or ACWR without a commensurate increase in injuries. Given these data, we recommend adopting outlier-based values for high ACWR and high acute workload. Future authors should validate the demarcations from our study among larger, diverse samples of swimmers. Swim teams with workloads much different from those of the team in this study may require different values. Furthermore, we caution coaches against treating acute workloads >37.2 km or ACWRs >1.56 as values student-athletes should never exceed. Instead, coaches should continually monitor student-athletes' well-being and readiness to determine whether they are prepared for a certain workload.[27]

Methodological Considerations and Limitations

Our injury definition yielded injury mechanisms, time loss, and injured body regions consistent with epidemiologic data.[4,28] Our methodological choice to rely on coach and student-athlete reports yielded 11 injured participants (29.7% of the sample). Although a student-athlete seeking medical attention did not constitute an injury in our study, we asked participants whether they had done so in our questionnaires. Only 4 of the 11 student-athletes reported seeking medical attention for their injury, which supports our methodological choice of coach- and self-report. Given our injury definition and reporting methods, overuse was the predominant injury mechanism, accounting for all but 1 injury. This finding is consistent with observations in a prior epidemiologic study[4] of collegiate swimmers, in which overuse was the most common injury mechanism. In addition, only 3 injuries affected participation for >4 days. These outcomes also correspond with epidemiologic data showing that swimming had the lowest rate of severe injuries (based on time loss) across NCAA sports.[28] Because swimmers tend to continue training in the presence of pain, however, this low severe injury rate likely underrepresents their prevalence of pain.[2,3] Finally, also in keeping with epidemiology data, the injured body regions we observed (shoulder, trunk, and knee) align with those in a previous epidemiologic report on collegiate swimmers.[4] Most of the swimming literature has been focused on the shoulder. Because nearly two-thirds of collegiate swimming injuries affect body regions other than the shoulder,[4] we recommend future investigations of injuries to all body regions and not just the shoulder.

The small number of participants and injuries in this study meant that the 95% CIs surrounding the ORs for both acute workload (95% CI = 8.2, 89.8) and ACWR (95% CI = 7.7, 81.4) were wide. Based on these wide CIs, readers should interpret the magnitude of the associations we noted with caution. To improve precision, future studies would benefit from multiteam samples or data from 1 team over several seasons. Furthermore, in addition to swimming, participants engaged in strength training. However, we did not assess the possible influence of strength training on injury. Moreover, it was not feasible to measure the student-athletes' internal workload (ie, heart rate or rating of perceived exertion), which represents their physiological or psychological response to imposed external workloads (distance swum).[27] With that said, researchers[29] studying swimmers have shown a strong correlation between rating of perceived exertion and distance swum ($r = 0.71$). Nevertheless, the relationship between injury and combined internal and external workload in swimmers remains unknown. In addition, in this study, external swimming workloads were coach- and self-reported. In accordance with our preliminary work verifying coach-reported workloads, authors[30] found that student-athletes complied with coach-prescribed training volume at a high rate. A low percentage of missing data further strengthened our workload data. Thus, although our data were limited to coach- and self-reported external swimming workloads, high compliance and response rates bolstered the data fidelity. Finally, our analyses did not incorporate intrinsic risk factors for injury. Given the multifactorial nature of an injury, a comprehensive approach to reducing risk should consider both extrinsic and intrinsic factors.[31]

CONCLUSIONS

High acute workload and ACWR were both associated with injury in collegiate swimmers; high overall and chronic workloads were not. Therefore, collegiate coaches may prescribe high workloads spread out over the season without increased injury odds. However, they should be cautious in prescribing high acute workloads and high ACWRs. In this sample, acute workloads $>$37.2 km/wk and ACWRs $>$1.56 corresponded with increases in injury rates, from $\leq$1% for typical workloads and ACWRs to 15% for high acute workloads and 14% for high ACWRs. More than half of the injuries occurred during the team's winter training trip. These data raise concerns about the risk of these high acute-workload trips, particularly when they occur after final examinations and winter break, which are often periods of reduced workloads. Moreover, one-third of the observed injuries occurred during the first 5 weeks of the season. Considering the potential inaccuracy of the self-reported preseason workload in this study, swimmers may still benefit from focusing on building their chronic workload in the preseason.

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