

Influence of Baseball Training Load on Clinical Reach Tests and Grip Strength in Collegiate Baseball Players

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Context: A baseball-specific training load may influence strength or glenohumeral range of motion, which are related to baseball injuries. Glenohumeral reach tests and grip strength are clinical assessments of shoulder range of motion and upper extremity strength, respectively.

Objective: To examine changes in glenohumeral reach test performance and grip strength between dominant and nondominant limbs and high, moderate, and low baseball-specific training-load groups.

Design: Repeated-measures study.

Setting: University laboratory and satellite clinic.

Patients or Other Participants: Collegiate baseball athletes ($n = 18$, age = 20.1 ± 1.3 years, height = 185.0 ± 6.5 cm, mass = 90.9 ± 10.2 kg).

Main Outcome Measure(s): Participants performed overhead reach tests (OHRTs), behind-the-back reach tests (BBRTs), and grip strength assessments using the dominant and nondominant limbs every 4 weeks for 16 weeks. Percentage change scores were calculated between testing times. After each training session, participants provided their duration of baseball activity, throw count, and body-specific and arm-specific ratings of perceived exertion. We classified them in the high, moderate, or low training-load group based on each

training-load variable: body-specific acute:chronic workload ratio (ACWR), arm-specific ACWR, body-specific cumulative load, and arm-specific cumulative load. Mixed models were used to compare training-load groups and limbs.

Results: The arm-specific ACWR group demonstrated as main effect for OHRT ($F = 7.70$, $P = .001$), BBRT ($F = 4.01$, $P = .029$), and grip strength ($F = 8.89$, $P < .001$). For the OHRT, the moderate training-load group demonstrated a 10.8% greater increase than the high group ($P = .004$) and a 13.2% greater increase than the low group ($P < .001$). For the BBRT, the low training-load group had a 10.1% greater increase than the moderate group ($P = .011$). For grip strength, the low training-load group demonstrated a 12.1% greater increase than the high group ($P = .006$) and a 17.7% greater increase than the moderate group ($P < .001$).

Conclusions: Arm-specific ACWR was related to changes in clinical assessments of range of motion and strength. Clinicians may use arm-specific ACWR to indicate when a baseball athlete's physical health is changing.

Key Words: throwing athletes, upper extremity, acute: chronic workload ratio

Key Points

- Baseball-specific training loads are related to clinical measures of range of motion and strength. It may be pertinent for clinicians to use a baseball-specific acute:chronic workload ratio to understand physical changes that may result from sport participation.
- The high and low training-load groups displayed changes in reach test performance. Clinicians should be vigilant when baseball-specific loads are high or low, as this may correspond with overtraining or undertraining.
- Arm-specific training loads should take into account all throws, not just competitive pitching throws, to supply better information about the true loads baseball players experience.

Baseball injuries primarily affect the shoulder and elbow¹ and may result from excessive participation and throwing load.² Previous researchers² indicated that those who threw the most pitches during a year were at a higher risk of injury, but recent investigators³ determined that pitch counts accounted for only 58% of all the throws a baseball pitcher made in a single game. Bullpen and warm-up throws could account for 42% more throwing load; this load metric does not include nonpitching activities, such as throws in the field, hitting, and base running. A more robust and comprehensive assessment of load is needed to better

quantify baseball participation. When throw counts and the rating of perceived exertion (RPE) were used to create session RPE (sRPE) load measures, throwing load was related to injury risk in cricket, a sport similar to baseball.⁴ Accounting for both *external load* (the measure of physical work) and *internal load* (the physiological or perceptual response to activity) may provide a more comprehensive assessment of baseball-specific load. When authors used the sRPE load to calculate acute:chronic workload ratios (ACWRs) and identify athletes who were overloading or underloading during training, the ACWR predicted injury

in cricket⁴ and soccer⁵ athletes. Both cumulative sRPE load measures and ACWR calculations may be useful for identifying when baseball athletes are at a higher risk of injury.

Changes in shoulder range of motion (ROM), including internal rotation,^{6,7} external rotation,⁸ total rotation,⁹ and flexion,¹⁰ have been linked to injury risk in baseball players. Scapular motion is also theoretically linked with injury,¹¹ although researchers¹² suggested that scapular dysfunction was not related to injury rates in baseball athletes. However, measures of ROM and scapular motion demonstrated suspect reliability and precision,¹³ and scapular mechanics were often limited to a qualitative analysis of scapulohumeral rhythm.¹² Clinical reach tests have emerged as reliable assessments that are linked to shoulder ROM¹⁴ and may be clinically useful for assessing gross changes to glenohumeral ROM and scapular movement.¹⁵

Shoulder strength has been implicated in injury risk as well, as baseball players who displayed less shoulder strength were at greater risk of injury that resulted in >3 days missed from sport or required surgery.¹⁶ Glenohumeral strength is difficult to measure in the clinical setting because results from handheld dynamometers can be influenced by the size, weight, sex, and strength of the tester.¹⁷ Clinically, it may be easier to assess simple grip strength, which has been related to glenohumeral strength.¹⁸ In baseball players, decreased grip strength was linked to restricted blood flow of the upper extremity in a provocative position¹⁹ and theorized to contribute to medial elbow-joint stability.²⁰

Clinical measures such as glenohumeral reach tests and grip strength provide athletic trainers with tools that can quickly supply information regarding glenohumeral strength and ROM. Implementation of these measures at regular intervals would be prudent for assessing changes in physical factors, but such protocols may miss critical times when training and playing schedules are more grueling. Training-load assessments that use sRPE load measures and ACWR calculations may provide a comprehensive assessment of baseball participation and indicate when athletes are overreaching in their training. Coupling training-load assessments with clinical measures of gross shoulder function may supply clinicians with evidence to alter training programs or insert additional rest days when needed. Therefore, the purpose of our study was to examine the percentage change in glenohumeral reach test performance and grip strength between the dominant and nondominant limbs of participants and among groups with high, moderate, or low baseball-specific training loads over a 4-week period. We hypothesized that the high training-load group would demonstrate the greatest negative changes in reach distance (decreased ROM) and grip strength compared with the moderate and low training-load groups.

METHODS

Research Design

Participants were active baseball players recruited from 2 collegiate baseball teams who were involved in the fall seasons of their respective teams ($n = 61$, age = 19.7 ± 1.2 years, height = 185.0 ± 6.5 cm, mass = 90.9 ± 10.2 kg).

Participants must have had access to the training-load surveys via a smartphone or computer. Exclusion criteria were pain or injury that limited participation currently or within the last 3 months, surgery within the last year, or a self-reported mental health disorder, including but not limited to anxiety, depression, or mood disorder.

A longitudinal, repeated-measures design was used. Study approval was obtained from the University of North Carolina at Chapel Hill Office of Human Research Ethics and Institutional Review Board. After providing informed consent, participants completed a playing and injury history form regarding their baseball experience to ensure that they met all the inclusion and no exclusion criteria. Once participants were enrolled, physical data-collection sessions were conducted at the preseason, 4-week, 8-week, 12-week, and 16-week time points throughout the fall season to obtain glenohumeral rotational ROM and grip strength. Participants completed daily training-load surveys on a computer or smartphone device. For their data to qualify for the statistical analysis, participants were required to answer at least 50% of the training-load and wellbeing surveys from the previous 28 days to correspond with the cumulative sRPE measures and chronic component of the ACWR calculation described in a subsequent section. After these a priori rules were applied, the final dataset contained 18 participants (age = 20.1 ± 1.3 years, height = 185.0 ± 6.5 cm, mass = 90.9 ± 10.2 kg) who were engaged in a total of 30 player testing sessions.

Physical Assessments

Glenohumeral Reach Tests. Glenohumeral reach tests were performed with the participant standing. A tape measure was placed over the length of the spine, and the origin (marked 0 on the tape measure) was secured at the most prominent point of the C7 spinous process. The participant placed the nontest arm on the same hip while the examiner tested the opposite arm. For both the overhead reach test (OHRT) and the behind-the-back reach test (BBRT), the participant was in the same position, with the tape measure secured in the same manner. For the OHRT, the participant placed the hand of the test limb on his head and began sliding it inferiorly down the spine as far as possible. Once the terminal distance was reached, the examiner recorded (centimeters) where the middle finger was on the tape measure (Figure 1A). For the BBRT, the individual was instructed to place the dorsal side of the hand at the level of the sacrum, make a “thumbs up” sign, and then slide his arm up the spine until he reached maximal distance, which was recorded (centimeters) as the point where the thumb touched the tape measure (Figure 1B). For the OHRT, a higher number indicated greater range of motion; for the BBRT, a lower number indicated greater range of motion. Each test was performed 3 times on the dominant and nondominant limbs, and the individual’s limb average was used for the statistical analyses. The percentage change from the most recent test was calculated and used for the statistical analyses for both the OHRT and BBRT. We demonstrated excellent test-retest reliability and precision for the OHRT ($ICC_{2,3} = 0.959$, $SEM = 1.35$ cm) and BBRT (intraclass correlation coefficient [ICC]_{2,3} = 0.915, $SEM = 1.35$ cm).

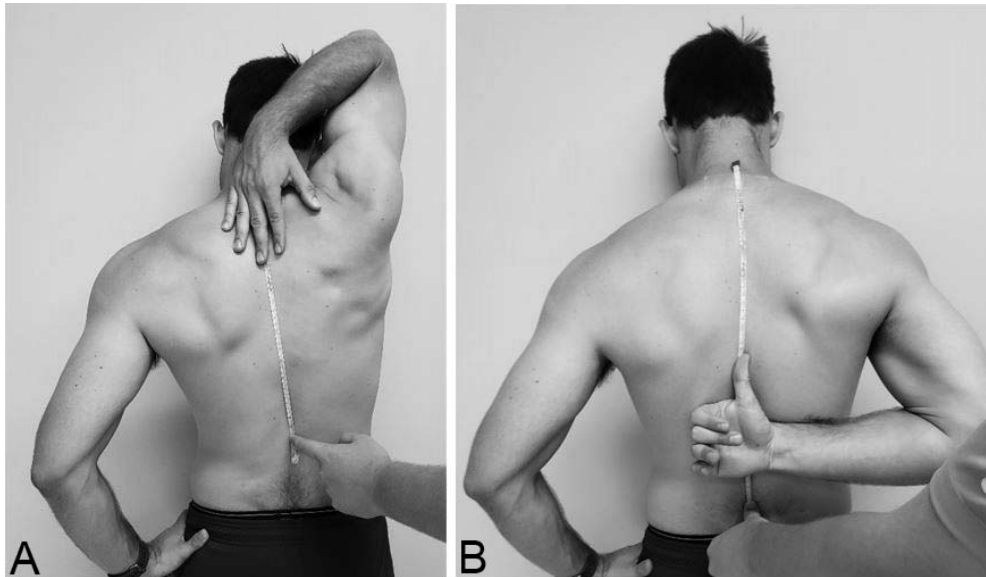


Figure 1. Functional reach test assessment method. A, Overhead reach test. B, Behind-the-back reach test.

Grip Strength. Grip strength assessments were performed with a calibrated handheld compression load-cell dynamometer (model TSD121C; BIOPAC Systems Inc, Goleta, CA) using methods similar to Horsley et al.¹⁸ Participants performed 1 trial of maximal grip strength that lasted for 3 to 6 seconds in 3 postures: shoulder in neutral and elbow flexed to 90°; shoulder abducted to 90° and elbow flexed to 90°; and shoulder abducted to 90° and externally rotated 90° and elbow flexed to 90° (Figure 2). Blood-flow decreases have been associated with decreases in grip strength in a fully abducted and externally rotated position,²¹ so we elected to use 3 postures for this assessment. Participants stood with their heels, buttocks, shoulders, heads, and elbows against a wall and performed a single trial in each posture; the average was used for data analysis. Previous testing in our laboratory demonstrated excellent test-retest reliability ($ICC_{2,3} = 0.936$) and precision ($SEM = 14.66$ N) for the grip strength assessment.

Training-Load Assessment. Training load was assessed via a survey that was developed to collect pertinent training variables feasibly and conveniently through a computer and

smartphone-based application (Qualtrics LLC, Provo, UT). The training-load survey information was collected each day after activity. This survey was designed to capture all aspects of training load associated with baseball participation. Participants reported the duration of their activity in minutes and the number of throws performed during baseball activity for the day. *Duration* was defined as the total time in minutes involved in all aspects of on-field and off-field baseball participation, strength training, and conditioning. A *throw* was defined as any throw other than for warm-ups, including long toss, flat ground, bullpens, live games, and fielding practice. (Low-intensity throws do not significantly increase joint loads, so we opted to remove warm-up throws from the definition.) Because throws >37 m demonstrate joint loads that are similar to baseball pitching,²² all throws were equally weighted.

Participants were asked to provide their RPE experienced during baseball activity and any current training session, recorded on a scale from 0 to 10, with 0 representing *no activity* and 10 representing *maximal exertion*.^{23,24} Participants provided RPEs for 2 body regions: total-body

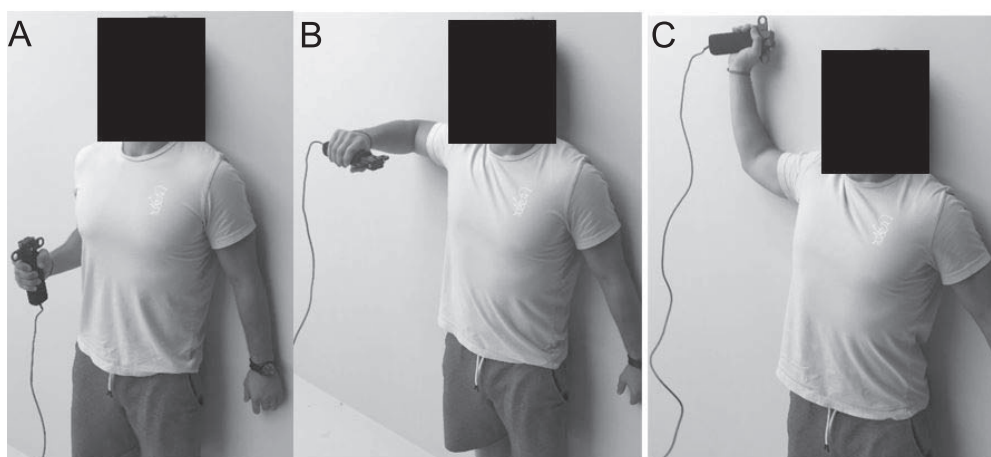


Figure 2. Grip strength assessment postures.

exertion and arm-specific exertion. Previous authors^{23,24} indicated that RPE showed high reliability and validity relative to heart-rate methods of assessing training impulse.

Data Reduction

Grip Strength Data. Grip strength data were sampled at 2000 Hz using a BIOPAC acquisition system (model MP150), and the raw force signals were exported as a text file on a personal computer. Grip strength data were reduced using custom software (LabVIEW version 17.0; National Instruments Corp, Austin, TX) on text files collected during the physical data-collection session. The force signals were low-pass filtered using a fourth-order, zero-phase shift Butterworth filter with a cutoff frequency of 50 Hz. Peak isometric force (Newtons) was identified as the highest 200-millisecond epoch during the maximal voluntary contraction. The average of the 3 trials for each strength test was used for analysis. The percentage change in grip strength from the previous test was used in the data analysis.

Training-Load Data. Data from the training-load assessment were first reduced into daily total loads. Daily total-body sRPE was calculated as the product of the duration of baseball activity (minutes) and total-body RPE, and daily arm-specific sRPE was calculated as the product of throw count and arm-specific RPE.

Given the compliance challenges in daily activity data collection, we were concerned about missing data. We plotted data responsiveness by day to ensure that these data were missing completely at random, and then missing data values were estimated using multiple imputation techniques.²⁵ This method is preferred over other types of imputation, such as single imputation, closest match, and standard likelihood methods.²⁶ Multiple imputation replaces missing values with pseudorandom values based on observed values within the dataset for a given individual while maintaining nonmissing data points within the dataset.²⁶ The predictive mean matching imputation procedure was performed multiple times on multiple datasets to enhance the accuracy of the missing data. To qualify for missing data analysis and retain the participant's data in the analysis, he must have responded to at least 50% of the previous 28 training-load surveys. This time frame was selected to correspond with the cumulative and chronic portions of the ACWR value. The percentage of responsiveness was selected to ensure that the imputed data would have adequate data from which we could draw results. Data from participants with <50% responsiveness could lead to inaccurate estimates and biased imputed data.²⁵ A total of 25 imputations were performed on 5 datasets, and these datasets were combined to create a single complete output, on which the statistical analyses were performed. Participant identifier, team, date, practice type, and playing position were used to impute missing data for the daily body-specific sRPE and daily arm-specific sRPE variables.

After imputation, 4 main outcome variables were calculated from the data collected on the Daily Training Load Assessment Survey: 4-week, body-specific cumulative sRPE; 4-week, arm-specific cumulative sRPE; body-specific ACWR; and arm-specific ACWR. To obtain the 4-week, body-specific cumulative sRPE, we summed the daily total body sRPEs for the 28 days preceding the

participant's physical data-collection session. To obtain the 4-week, arm-specific cumulative sRPE, we summed the daily arm-specific sRPEs for the 28 days preceding the participant's physical data-collection session. The body-specific ACWR was calculated as the average daily body-specific sRPE of the 7 days before the physical data-collection session divided by the average daily body-specific sRPE of the 28 days before the session. The arm-specific ACWR was calculated in a similar manner: the average daily arm-specific sRPE of the 7 days before the physical data-collection session was divided by the average daily total body load of the 28 days before the session. Similar to previous researchers,²⁷ we categorized training-load variables (body-specific cumulative sRPE, arm-specific cumulative sRPE, body-specific ACWR, and arm-specific ACWR) into high, moderate, and low training-load groups. The groups were divided evenly into tertiles; the 30 total player testing sessions were divided into 10 player sessions in each group. The training-load groups were used as the independent variables in the statistical analysis.

Statistical Analysis

To ensure that the training-load groups were different, we performed paired *t* tests with a Bonferroni correction on the load variables between training-load groups. The percentage changes ($[\text{Posttest} - \text{Pretest}/\text{Pretest}] \times 100$) in OHRT, BBRT, and grip strength were compared between training load groups and limbs with separate random intercept mixed models. Our 18 participants combined for 30 separate player sessions, so the model used participant as a random intercept to account for participant re-entry into the analysis. The percentage changes in OHRT, BBRT, and grip strength from the previous physical testing session served as the dependent variables in each analysis. The fixed effects were limb (dominant, nondominant) and training-load group (high, moderate, low). Separate models were conducted for each body-specific and arm-specific cumulative sRPE and ACWR training-load group. Four models in total were generated for each dependent variable. Interactions and main effects were deemed significant at $P < .05$, and all post hoc testing was performed with Bonferroni corrections for multiple comparisons ($P < .016$). Cohen *f* effect sizes (ESs) were calculated for the interaction and main effects via the variance associated with each fixed effect. Cohen *d* effect sizes were computed between groups, and 95% confidence intervals were calculated for parameter estimates of the group means and differences between groups. All analyses were performed in R software (R Foundation, Vienna, Austria).

RESULTS

Descriptive Statistics

For body-specific and arm-specific cumulative sRPE, participants in the high training-load group demonstrated greater values than the moderate ($P < .01$) and low ($P < .01$) training-load groups, and those in the moderate training-load group exhibited greater values than the low training-load group ($P < .01$). For body-specific and arm-specific ACWR, participants in the high training-load groups displayed higher values than the moderate ($P < .01$) and low training-load groups ($P < .01$), and those in

Table. Training-Load Group Results

Training-Load Variable	Training-Load Group (Mean ± SD) ^a		
	High	Moderate	Low
Acute : chronic workload ratio			
Arm specific ^b	1.62 ± 0.41	1.06 ± 0.11	0.63 ± 0.17
Body specific ^b	1.39 ± 0.47	0.79 ± 0.04	0.36 ± 0.20
4-Wk session rating of perceived exertion			
Arm specific ^b	3095.00 ± 791.28	1630.00 ± 162.81	973.00 ± 432.06
Body specific ^b	25 027.59 ± 8324.85	12 508.22 ± 1796.05	6070.20 ± 2336.62

^a All data presented in arbitrary units (AUs).

^b Indicates that the high, moderate, and low training-load groups were all different.

the moderate training-load group had higher values than the low training-load group ($P < .01$). The descriptive data for the training-load groups are presented in the Table.

Overhead Reach Test

No significant interaction effect existed between limb and training-load group for any of the training-load variables regarding the percentage change in OHRT. We observed no significant main effect for limb ($F = 0.10$, $P = .757$), suggesting that the dominant and nondominant limbs demonstrated similar changes.

As for the training load groups, a main effect of arm-specific ACWR group on the percentage change in OHRT performance was apparent ($F = 7.70$, $P = .001$, $ES = 0.61$). After participant as a random intercept was accounted for, pairwise comparisons indicated the high training-load group demonstrated a 10.8% greater negative change than the moderate training-load group (95% CI = 3.5%, 18.1%; $P = .004$; Cohen $d = 1.04$), and the moderate training-load group displayed a 13.2% greater positive change than the low training-load group (95% CI = 6.1%, 20.2%; $P < .001$; Cohen $d = 1.05$), suggesting the moderate group produced the most positive change of the 3 groups (Figure 3A). A main effect of arm-specific cumulative sRPE on the percentage change in OHRT occurred ($F = 4.50$, $P = .017$, $ES = 0.48$). The high training-load group had a 10.7% greater positive change in OHRT than the low training-load group (95% CI = 3.1%, 18.2%; $P = .006$; Cohen $d = 0.856$). A main effect of body-specific cumulative sRPE training-load group on the percentage change in OHRT ($F = 3.49$, $P = .041$, $ES = 0.40$) was present. When comparing group means, we found that the high training-load group showed a 9.9% greater positive change in OHRT than the low training-load group ($P = .012$, Cohen $d = 0.847$). No main effect of body-specific ACWR on the percentage change in OHRT occurred. Figure 3 illustrates the percentage change in OHRT by training-load group and limb for each training-load variable.

Behind-the-Back Reach Test

No significant interaction was present between limb and training load group for any of the training load variables on the BBRT. No significant main effect of limb existed for the percentage change in the BBRT ($F = 1.73$, $P = .197$), suggesting that the dominant and nondominant limbs demonstrated similar changes.

For the training-load groups, we noted a significant main effect of arm-specific ACWR training-load group on the

percentage change in BBRT results ($F = 4.67$, $P = .014$, $ES = 0.45$). After we accounted for participant as a random intercept, pairwise comparisons revealed that the moderate training-load group had a 10.1% greater positive change than the low training-load group (95% confidence interval [CI] = 2.4%, 17.7%; $P = .011$; Cohen $d = 1.08$). An 8.9% greater negative change was evident in the low training-load group compared with the high training-load group that approached significance, but after accounting for the multiple comparisons, we found that it was not statistically significant (95% CI = 1.55%, 16.0%; $P = .017$; Cohen $d = 0.87$).

A main effect of body-specific cumulative sRPE training-load group was present for the percentage change in BBRT performance ($F = 4.94$, $P = .011$, $ES = 0.53$). After participants were accounted for, the low group demonstrated an 11.7% greater positive change than the moderate group (95% CI = 4.1%, 19.3%; $P = .001$; Cohen $d = 0.31$), but the effect size indicates this may not be clinically significant. No significant main effect was observed for arm-specific cumulative sRPE training load group ($F = 0.23$, $P = .793$) or body-specific ACWR training load group ($F = 2.71$, $P = .076$). Figure 4 shows the percentage change in BBRT by training-load group and limb for each training-load variable.

Grip Strength

No significant interaction effect between limb and training-load group existed for any of the training-load variables regarding the percentage change in grip strength. We found no significant main effect of limb on percentage change in grip strength ($F = 0.14$, $P = .71$), suggesting that the dominant and nondominant limbs demonstrated similar changes.

As for the training-load groups, a main effect of arm-specific ACWR training-load group on the percentage change in grip strength was evident ($F = 8.89$, $P < .001$, $ES = 0.77$). Pairwise comparisons of the parameter estimate of the training-load groups indicated that the low training-load group demonstrated a 17.7% greater positive change than the moderate group (95% CI = 3.5%, 20.6%; $P = .006$; Cohen $d = 0.48$) and a 12.1% greater positive change than the high group (95% CI = 3.5%, 20.6%; $P < .001$; Cohen $d = 0.69$). No main effect was present for arm-specific cumulative training-load group ($F = 0.23$, $P = .796$), body-specific ACWR training-load group ($F = 1.86$, 0.166), or body-specific cumulative training-load group ($F = 0.29$, $P = .744$) on the percentage change in grip strength. Figure 5 describes the percentage change in grip strength by

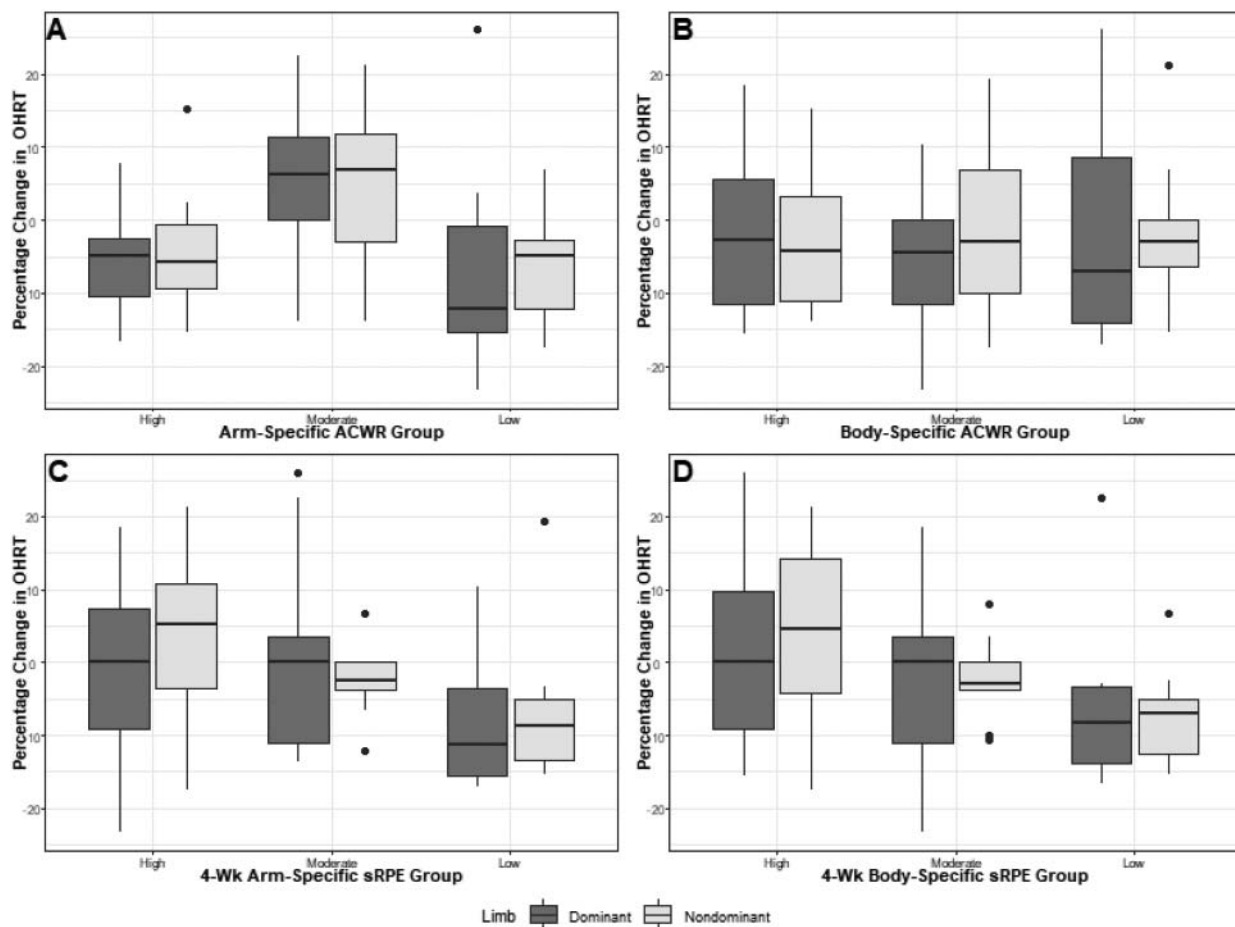


Figure 3. Percentage change in the overhead reach test (OHRT) by training-load group and limb. **A**, Arm-specific acute:chronic workload, **B**, body-specific acute:chronic workload (ACWR), **C**, arm-specific cumulative session rating of perceived exertion (sRPE), and **D**, body-specific cumulative session rating of perceived exertion.

training-load group and limb for each training-load variable.

DISCUSSION

Our results indicated that arm-specific ACWR demonstrated an influence on all 3 clinical measures of strength and ROM. For the OHRT, participants in the moderate training-load group exhibited an increased reach distance compared with the low and high training-load groups, which was a positive change. This finding differed from our hypothesis: we theorized that the high training-load group would show the greatest negative changes in reach distance. Grip strength increased when participants demonstrated a low ACWR, indicating that grip strength improved when the arm-specific load was lower in the current week than in the previous 4 weeks. For the BBRT, participants with the lowest ACWR demonstrated a decrease in ROM, as lower scores on the BBRT correspond with higher internal-rotation scores.²⁸ Although the reach tests revealed differences between the body-specific cumulative sRPE and ACWR training-load groups and arm-specific cumulative sRPE training-load groups, no consistent trend was apparent across all dependent variables; thus, these training-load variables may not indicate when clinical measures of ROM and grip strength are changing. Our data suggest that arm-specific ACWR was related to clinical

measures of ROM and grip strength, potentially reflecting the clinical usefulness of this training-load variable.

Injuries in baseball players are likely influenced by the amount of baseball participation.² Although high pitch counts in baseball players have been linked with arm pain²⁹ and changes in shoulder strength,²⁷ recent researchers³ found that pitch counts accounted for only 58% of the throwing load in a given game, with the remaining 42% attributable to warm-up throws, bullpen throws, and fielding throws. This value also fails to account for the effects of weight training, arm care exercises, and sport-specific training, all of which may influence the injury risk in baseball players. Quantifying both the external and internal loads demonstrated significant utility in predicting injuries in cricket, an overhead sport similar to baseball.⁴ We used the sRPE measure from a more classic total body perspective (duration and total-body RPE) and an arm-specific perspective (throw count and arm-specific sRPE). The arm-specific ACWR influenced changes in each of the dependent variables, indicating that the arm-specific ACWR may be useful for quantifying overall baseball participation. The ACWR quantified both the total number of throws made by the participant and the internal perception of difficulty, assessed via an arm-specific RPE. This assessment technique may provide a more comprehensive metric of baseball participation and could be used

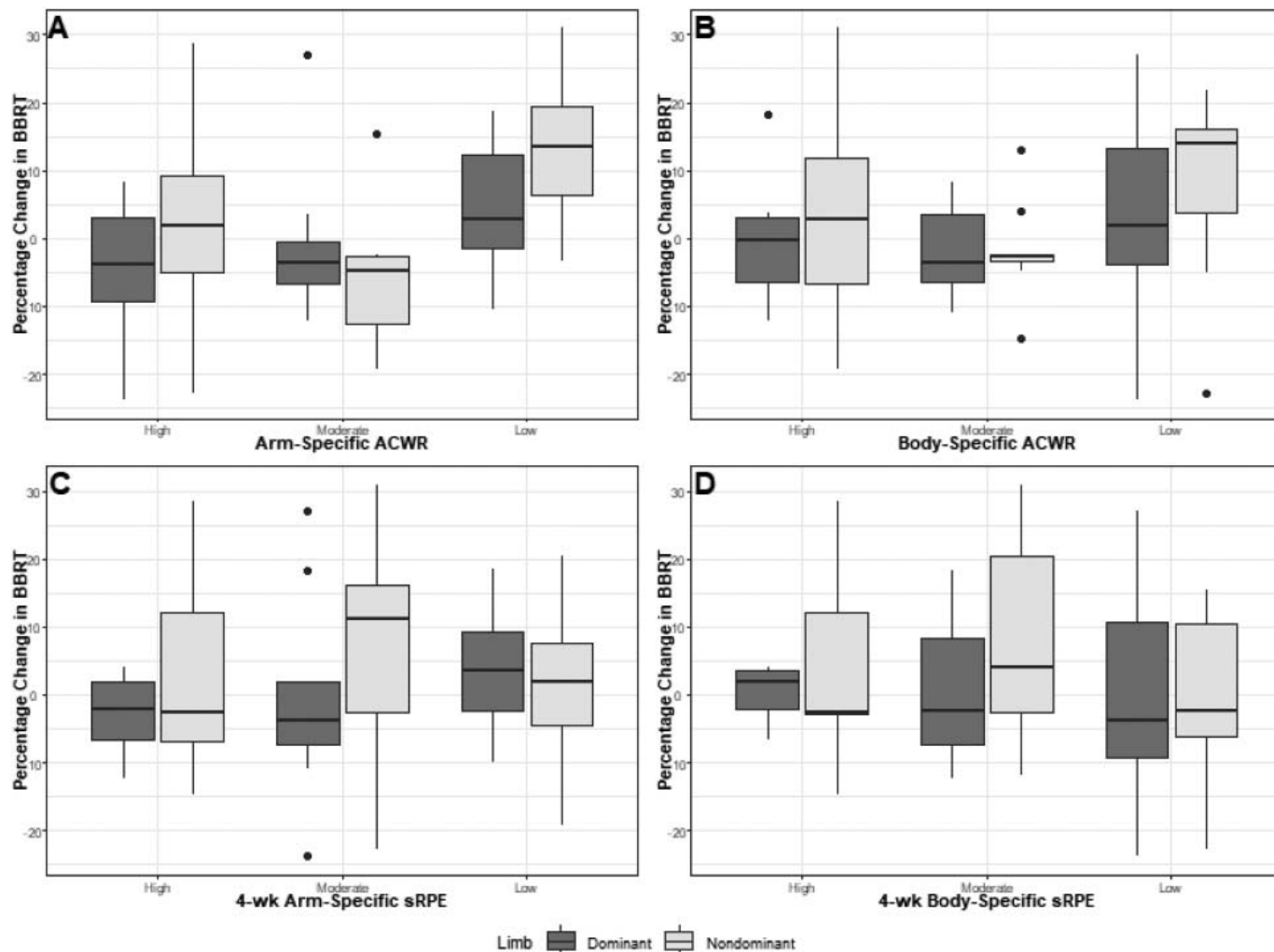


Figure 4. Percentage change in the behind-the-back reach test (BBRT) by training-load group and limb. **A**, Arm-specific acute : chronic workload, **B**, Body-specific acute : chronic workload (ACWR), **C**, Arm-specific cumulative session rating of perceived exertion (sRPE), and **D**, Body-specific cumulative session rating of perceived exertion.

as load-monitoring model in overhead athletes. The lack of an interaction effect indicates that the arm-specific ACWR may not address local muscle effects but rather global activity, similar to total-body ACWR outcomes in field sports. Future investigators should continue to use and develop this method and evaluate how this method might predict injury or account for progress in postinjury rehabilitation in baseball players.

Previous authors^{7,8} determined that limited shoulder ROM was implicated in throwing injuries among baseball athletes. Limited internal- and external-rotation ROM has been associated with elbow⁷ and shoulder injuries.⁸ Although scapular mechanics were not prospectively linked with injuries in baseball players,¹² a theoretical link between scapular characteristics and injury in overhead athletes is still possible.¹¹ The throwing motion significantly taxes the glenohumeral joint and scapulothoracic articulation, leading to a change in rotator cuff ROM.³⁰ This muscle stress from baseball throwing likely affects multiple muscles about the shoulder region. The OHRT and BBRT are gross assessments of shoulder physical function and address movements at the humeroulnar joint, glenohu-

meral joint, and scapulothoracic articulation. Earlier researchers²⁸ indicated that the BBRT result was related to internal-rotation ROM, but minimal evidence suggests a link between OHRT performance and any other flexibility measures. Theoretically, a decrease in glenohumeral elevation in either the frontal or sagittal plane or decreased scapular upward rotation could manifest as a shorter reach on the OHRT. We identified a positive ROM change when the ACWR was closest to 1, but the source of these changes is not clear. Although we suspect that the change in OHRT performance reflected a combination of glenohumeral and scapulothoracic changes, this is purely hypothetical and not a factor we investigated. Future authors should study the OHRT in more detail to understand whether changes in outcomes correspond with changes in humeroulnar, glenohumeral, or scapulothoracic ROM.

Grip strength is critical for protecting the medial elbow joint in baseball athletes. Baseball pitching creates elbow valgus loads of >90 Nm,²² but the ultimate failure point of the ulnar collateral ligament is 36 Nm.³¹ The dynamic contribution of the medial forearm muscles is critical for providing an internal varus moment that counteracts the

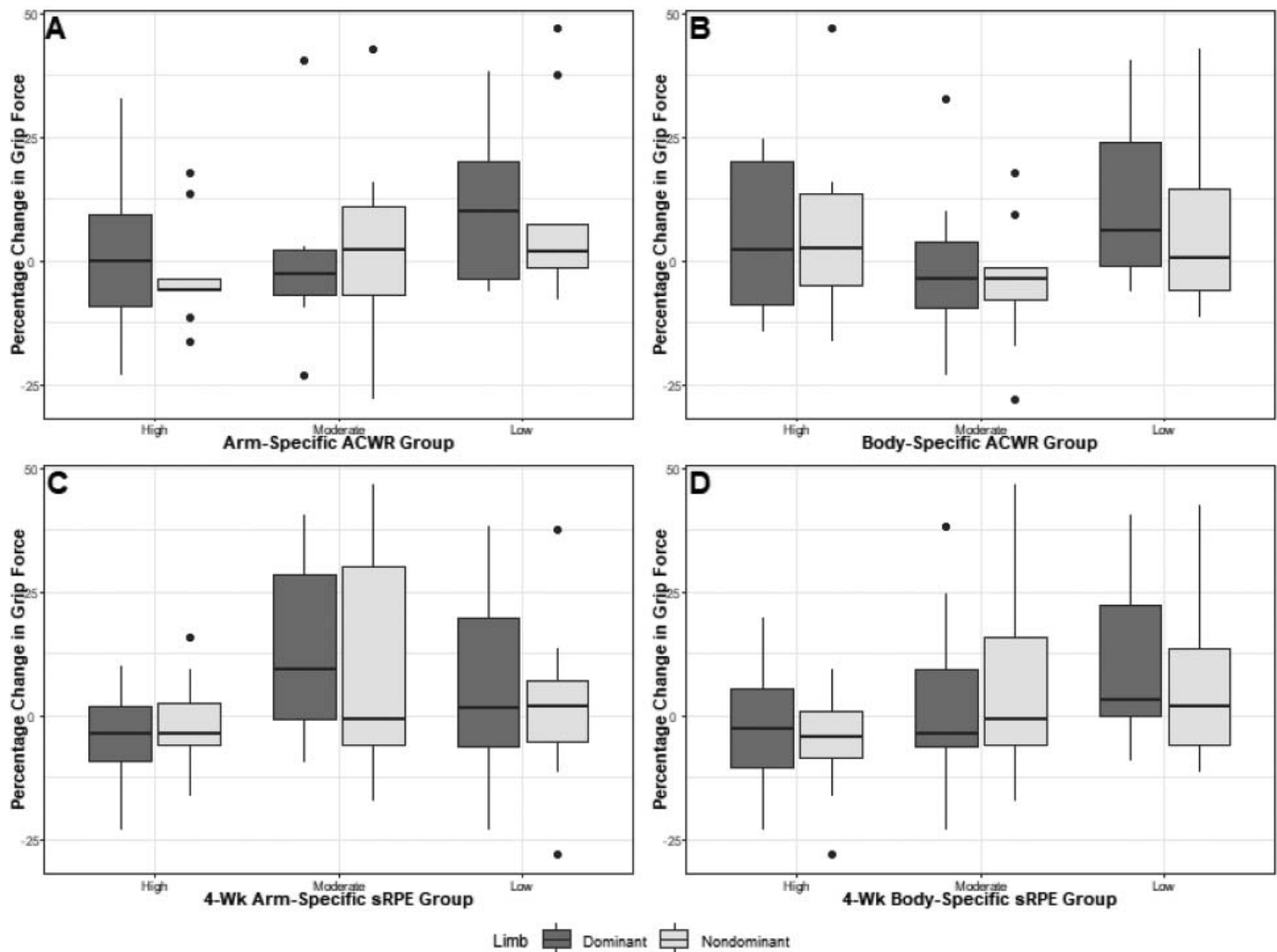


Figure 5. Percentage change in grip strength by training-load group and limb. **A**, Arm-specific acute : chronic workload, **B**, body-specific acute : chronic workload (ACWR), **C**, arm-specific cumulative session rating of perceived exertion (sRPE), and **D**, body-specific cumulative session rating of perceived exertion.

elbow valgus load during throwing.²⁰ We used grip strength to assess the strength of the medial forearm musculature and learned that it increased the most when the ACWR was at its lowest. This information could be useful for repeated clinical assessments. If baseball players demonstrate decreased grip strength, coaches and clinicians may want to consider the recent training load to identify if they are experiencing a high, moderate, or low arm-specific ACWR training load. Decreasing the acute load may be beneficial in allowing grip strength to increase. Clinicians may also consider our results when creating throwing programs for those returning to pitching after injury or preparing for a competitive period. Building fitness with short windows of a moderate-load arm-specific ACWR may be useful in increasing grip strength during a throwing program. We hope that appropriately prescribing the throwing load in this manner will decrease early-season injuries, when injury rates are highest in high school baseball players.³²

The clinical measures in the current study are critical for athletic trainers who work with many athletes. These methods are reliable,¹⁴ clinician friendly, time efficient, and comparable with rotational ROM measures.²⁸ Additionally, the reach tests have face validity, as they require motion at

the glenohumeral joint and scapulothoracic articulation to attain maximal distance. A major benefit of the 3 assessment methods we used is minimal influence of tester subjectivity on the outcome measures. Traditional rotational ROM assessments require clinician expertise to determine the appropriate amount of overpressure and stabilization.¹³ This can lead to questionable reliability, making the determination of clinical meaningfulness very difficult. The drawbacks to the reach tests and grip strength are that they are not linked with injury risk but only theorized to contribute to injury. Despite these drawbacks, reach test and grip strength assessments may provide utility as quick screening tools for determining when baseball players demonstrate negative changes. Clinicians may then be able to perform further physical examination to determine if an athlete requires a therapeutic exercise intervention.

Our study had limitations. The initial sample enrolled was almost 3 times larger than the final sample, but we experienced compliance challenges that led to exclusion of a significant portion of the sample. Future researchers should address compliance and develop a plan a priori to account for missing data. The participants consisted of a

convenience sample of collegiate baseball players (both position players and pitchers) who were competing in the fall season. Collegiate baseball players only participate on 1 team and have a dedicated strength and conditioning coach and athletic trainer. Future researchers should assess younger athletes who play on multiple teams and do not have access to the same resources, as they may react differently at higher training loads. Baseball athletes were asked to respond to the training-load survey within 30 minutes after activity, but we could not control for this temporal factor. Recall bias may have played a role in training-load reporting, so future investigators should identify the best methods for evaluating training loads via smartphone and computer.

CONCLUSIONS

Arm-specific ACWR demonstrated significant effects on shoulder reach and grip strength changes in collegiate baseball players. Future assessors of training load in baseball players may want to consider arm-specific training loads. The use of sRPE measures is also recommended, as considering both the external and internal training loads may provide a more comprehensive quantification of baseball participation. Coaches and clinicians can use sRPE-type measures to create throwing programs and determine when baseball participation may be too strenuous for a specific player.

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