THE INFLUENCE OF TRAINING LOAD ON MUSCULOSKELETAL INJURY RISK
VARIABLES, OBJECTIVE FATIGUE, SUBJECTIVE WELL-BEING, AND
PERFORMANCE IN BASEBALL ATHLETES

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ABSTRACT

Brett Steven Pexa: The Influence of Training Load on Musculoskeletal Injury Risk
Variables, Objective Fatigue, Subjective Well-Being, and Performance in Baseball
Athletes
(Under the direction of Eric D. Ryan and Joseph B. Myers)

Baseball's unique sport demands lead to a high prevalence of time-loss injuries.

Previously identified injury risk factors in baseball include decreased shoulder strength,

decreased shoulder range of motion, increased self-reported fatigue, excessive

participation and limited rest and recovery. Sport participation may be monitored via

training loads, which longitudinally track the physical work performed and the perception

of difficulty of activity to identify when excessive participation occurs. Excessively high

training loads and large changes to training loads influence injury risk in field sports, but

there is no evidence in baseball players to indicate if training loads influence changes to

musculoskeletal variables linked to injury. The purpose of this research study was to

determine the influence of training load on musculoskeletal injury risk variables,

objective fatigue measures, subjective well-being measures, and baseball performance.

Baseball players were assessed every 4 weeks over the course of the fall semester for

musculoskeletal injury risk variables, and objective fatigue measures. Participants

provided daily reports of baseball-specific training load and subjective well-being

variables. Baseball performance variables, average weekly fastball speed, weekly

average fastball spin, and weekly average exit velocity were collected at each

competition during the fall season. The results from this study indicate that baseball

specific training load has significant effects on subjective well-being measures, including weekly average readiness, weekly average stress, and weekly average soreness. Baseball-specific training load had a mild effect on very few musculoskeletal injury risk variables and objective fatigue measures, including the functional reach tests and grip strength. There was almost no effect of baseball-specific training load on shoulder rotation range of motion, shoulder strength, single leg bridge test, jump height, jump power, or any baseball performance variable. Baseball-specific training loads influence variables that may play a role in illness and injury in athletes, so utilizing training loads to monitor baseball participation may be useful to determine when baseball players are at risk for injury and illness. Future research should continue to investigate baseball-specific training loads to understand how they specifically influence injury risk in baseball players.

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LIST OF ABBREVIATIONS

ACWR—Acute-to-Chronic Workload Ratio

BBRT—Behind the Back Reach Test

CMJ—Countermovement Jump

ERPF—Glenohumeral External Rotation Peak Force

ERG—External Rotation Gain

FB—Fastball

GIRD—Glenohumeral Internal Rotation Deficit

HHD—Handheld Dynamometer

ID—Subject Identification

IRPF—Glenohumeral Internal Rotation Peak Force

LOWESS—Locally Weighted Scatterplot Smoothing

OHRT—Overhead Reach Test

RPE—Rating of Perceived Exertion

SLAP—Superior Labrum, Anterior to Posterior

SLBT—Single Leg Bridge Test

sRPE—Session Rating of Perceived Exertion

$sRPE_{Arm}$—Daily Arm-Specific Session Rating of Perceived Exertion

$sRPE_{Body}$—Daily Body-Specific Session Rating of Perceived Exertion

TROM—Total Rotational Range of Motion

UCL—Ulnar Collateral Ligament

CHAPTER 1: INTRODUCTION

Baseball participation has increased at the amateur level over the last 6 years.[1–3] The rise in participation is accompanied by an increase of injury, with more injuries being recorded over this time in amateur and professional baseball players.[4,5] Pitchers specifically are at a high risk of injury, with up to 27% of pitchers reporting an injury during their career.[6,7] Many of these injuries require significant time lost from participation,[5,8–10] and the average amount of time lost is between 21-53 days.[9,11,12] Recent evidence suggests that ulnar collateral ligament (UCL) injury rates have grown at a yearly rate of 9% in youth and adolescent athletes.[13] In addition to the high rate of upper extremity injuries in pitchers,[5,12] all baseball players regardless of position, may be at risk for time-loss injuries to the lower extremity and trunk.[5,10] Approximately 25% of injuries in pitchers and 60% of injuries in fielders affect the lower extremity and trunk regions.[9] In fielders, there is a high prevalence of hamstring injuries and hip/groin pathology that develops from non-contact mechanisms.[10,11] Baseball sport demands include running, fielding, hitting and throwing, but due to the frequency and time loss concerns of upper extremity injuries, research focuses on the throwing motion as a primary mechanism of injury in the upper and lower extremities.

Baseball Specific Injury Risk Factors

Baseball throwing utilizes unique whole-body sequencing, with each proximal segment generating speed for distal segments.[14] This summation of speed allows baseball players to impart high force on the ball, but also creates very fast body

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movements and high joint loads.[14–16] During the throwing motion, baseball players create angular velocities exceeding 3600 degrees per second at the elbow and 7000 degrees per second at the shoulder,[17–20] which are considered to be some of the fastest movements in sport. These high angular velocities lead to very high joint loads, which reach elbow varus torques of over 90 Nm[19–21] and shoulder proximal forces up to 1.5 times body weight.[15,16,20,22] To assist with joint stabilization, considerable activation of contractile tissue is required at the shoulder[23] and elbow[24–27] during the throwing motion, leading to changes in range of motion, [28–30] strength,[31] muscle morphology,[28,32] and self-reported pain and fatigue following activity.[32,33] These changes are consistent with results from laboratory-based muscle fatigue and damage studies.[34–36] Decreased strength, range of motion, and self-reported pain and fatigue demonstrate a return to a baseline state within 3 days of baseball participation.[28,30,32] Participation prior to full musculoskeletal recovery may lead to an accumulation of negative changes. This is problematic, as these changes have been identified as baseball specific injury risk factors.[37–44]

Baseball specific intrinsic injury risk factors include decreased range of motion and strength of the upper extremity. Injured pitchers demonstrate significantly lower glenohumeral internal rotation range of motion in their throwing arm compared to the non-dominant limb.[45–47] Glenohumeral external rotation difference of over 5 degrees side-to-side at preseason is associated with injury during the subsequent season.[37] While internal and external rotation range of motion are independently associated with injury, decreased glenohumeral total range of motion (the sum of glenohumeral internal rotation and external rotation) may be a better measure of glenohumeral range of

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motion, as it accounts for humeral torsion[48,49] and is linked to throwing injury.[37–40] Glenohumeral total range of motion deficits of over 5 degrees between the dominant and non-dominant arm have been linked to injury in prospective and case-control studies.[37–40] Dominant arm strength deficits may also increase injury risk, as evidence suggests rotator cuff strength at the preseason is related to throwing injuries during the subsequent year.[41–44] It is hypothesized that range of motion and strength deficits develop from repetitive microtrauma to the musculoskeletal system during the throwing motion.[29,50] The repeated nature of baseball throwing causes this microtrauma to accumulate, leading to changes within the glenohumeral soft tissue that manifest as changes to strength and range of motion.[32,51] Participation habits are very important to monitor, as excessive throwing or improper recovery may lead to the accumulation of this repetitive microtrauma.

Excessive participation, inadequate rest and recovery between participation, and participation despite feeling fatigued are considered extrinsic injury risk factors in baseball players.[52,53] Previous research demonstrates injured baseball players throw more pitches per game, innings per game, pitches per year, innings per year, and games per year.[54–56] Increased participation creates fewer days of rest between practice or competition, and inadequate rest and recovery is related to increased injury risk at the elbow in baseball players.[57] Participating with fewer days rest may also cause athletes to participate with more muscular fatigue, as strength and range of motion changes don't recover for up to 3 days.[30,36,58] Self-reported fatigue is a major risk factor of throwing injury.[54,55,59,60] Pitchers who participate despite feeling fatigued are 7-36 times more likely to sustain an injury than those who report no fatigue.[54,59,60] Excessive

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participation and limited recovery time could compound the effects of intrinsic risk factors, leading to further negative changes in previously compromised range of motion and strength.[28] By monitoring the amount of participation and changes to intrinsic risk factors simultaneously, research may identify how extrinsic risk factors affect changes to musculoskeletal injury risk factors and objective measures of fatigue.

Training Load Assessments

Training load assessments aim to quantify sport participation by utilizing measures of internal and external load. Internal load is the physiologic reaction or perception of training and is quantified via rating of perceived exertion (RPE), heart rate, volume of maximal oxygen uptake, and/or visual analog scale.[61,62] External load is the physical work that is performed during exercise and can be measured in time, steps, mileage, speed of running, and/or total throws.[63] Extrinsic risk factors in baseball can be considered external load measures, such as amount of throws per year, throws per game, or amount of competitions per year.[54–56] The product of internal and external load is the total training load, which quantifies the overall load experienced by an athlete during the single bout of training,[64] and is often expressed as session rating of perceived exertion (sRPE). When assessed longitudinally, large changes in sRPE can be quantified with the acute-to-chronic workload ratios (ACWR).[63,65,66] The ratios are created by taking the quotient of the current 1 week average total training load, considered a quantification of fatigue, and the rolling 4 week average total training, considered the fitness an individual has attained.[62,65,67–69] The ACWR indicates when the current training exceeds what the athlete has previously experienced. When an athlete trains, they develop fitness through training over a long period of time, which

corresponds to higher tissue resiliency and higher aerobic capacity.[62,66] Consecutive high external and/or internal loads will cause large increases in total training load, potentially increasing fatigue. High fatigue will lead to negative training effects, lower tissue resiliency, and decreased sport performance.[62,66] High ACWR has identified those at risk for injury in cricket,[65,68,70–72] Australian football,[67,69] rugby,[73] and soccer.[74]

While training load assessments have demonstrated an ability to identify those at risk for injury, a recent systematic review indicates that training load assessments are not well developed in upper extremity sports, specifically baseball.[61] In other upper extremity dominant athletes, cumulative total training loads and ACWR are predictive of injury.[65,68,73] Although internal and external load assessments have yet to be combined to predict injury in baseball players, high external loads, assessed via pitch count, have demonstrated associations with injury.[55,56,75] Additionally, Lyman et al.[56] demonstrated that pitchers who throw more than 600 pitches per season or less than 300 pitches per seasons are at higher risk of injury than those who throw between 300-600 pitches per season. This may indicate that those who throw excessively have higher fatigue levels, while those who throw to little may have insufficient arm fitness to tolerate a subsequent throwing bout. Both insufficient fitness and excessive training will create a high ACWR, which has been predictive of injury in other overhead sports.[65,68,70–72] Internal loads have not been recorded longitudinally but do change as a result of a single baseball pitching bout. Both RPE[33,76] and blood biomarkers[76,77] demonstrate change as a result of baseball participation. Previous literature[33,55,56,75–77] indicates that baseball pitchers experience changes to internal and external load scores, so tracking these longitudinally over a season may assist in identifying precursors to injury. Whether it is in pitchers or

fielders, monitoring external loads via throw counts and internal loads via sRPE may provide information regarding fatigue state.

Baseball participation causes a high burden of time-loss injury, so there exists a need to find innovative ways to limit injury risk. Repeated measures of intrinsic risk factors (glenohumeral range of motion and strength) may provide information regarding potential injury risk but requires significant time commitment and equipment that may not be present in amateur baseball settings. Objective fatigue measures, such as countermovement jump and grip strength assessment, incorporate powerful movements to assess the force producing capability of contractile tissue and may provide information about fatigue state.[78–80] Training load assessments that incorporate external and internal load measures of baseball participation may provide significant utility, because of their cost-effectiveness and accessibility. Due to the unique sport demand, baseball specific training load assessments must be able to capture loads associated with throwing, hitting, running, and fielding. The development of a baseball specific training load model may lead to early identification of athletes at risk for injury, thereby allowing for early intervention to reduce the incidence of major time-loss injury. Additionally, training loads may influence baseball performance, as previous evidence suggests that changes to baseball performance may be predictive of injury.[81,82] A baseball specific training load model related to musculoskeletal injury risk variables, objective fatigue, self-reported fatigue and soreness, and performance measures could be a powerful tool for players, parents, coaches, and clinicians to identify those at risk for injury.

Statement of Purpose

The purpose of this project is to determine how baseball-specific training load influences musculoskeletal injury risk variables, objective fatigue measures, subjective well-being measures, and performance variables in baseball players. The baseball specific training load assessment captures all aspects of baseball participation including throwing, hitting, fielding, running, weight training, and conditioning via a smartphone and/or computer-based survey that is easily accessible to baseball players. The baseball specific training load assessment provides information to coaches, players, parents, and clinicians regarding appropriate amount of training and participation. Additionally, the baseball specific training load assessment can be used to monitor baseball players return to throwing or hitting from long offseason breaks or return from injury.

Operational Definitions

Musculoskeletal Injury Risk Variables: Physical characteristics that are theorized to contribute to injury in baseball players. Variables included in this definition are glenohumeral total range of motion, glenohumeral overhead and behind the back functional reach tests, glenohumeral internal and external rotation peak force, and single leg bridge test.

Objective Fatigue Measures: Clinical tests used to determine the presence of neuromuscular fatigue as a result of physical activity. Variables included in this definition are the countermovement jump height and power and grip strength.

Subjective Well-Being Measures: Self-reported reports of readiness, fatigue, stress, and soreness that result from physical activity.

Baseball Performance Variables: Baseball specific variables that contribute to the success of the individual at their respective position. For pitchers, these variables include weekly average fastball speed and weekly average fastball spin. For position players, this definition includes weekly average exit velocity on balls hit in the field of play.

Baseball-specific training load: Baseball-specific training variables that quantify baseball participation from both an arm-specific and total body perspective. This includes throw count, duration of all baseball activity, arm-specific RPE, and total body RPE.

Specific Aims and Hypotheses

Specific Aim 1

To determine the association between baseball specific training load (arm-specific and body-specific 4-week cumulative sRPE and ACWR) and percent change from baseline of musculoskeletal injury risk variables (glenohumeral total range of motion, glenohumeral rotational strength, functional reach tests, single leg bridge test) in collegiate baseball players.

Hypothesis 1: There will be a negative relationship between baseball specific training load and the musculoskeletal injury risk variables' percent change from baseline. This indicates that athletes with high cumulative loads and high ACWR will demonstrate

decreased glenohumeral range of motion, glenohumeral strength, functional reach test, and single leg bridge repetitions from baseline.

Specific Aim 2

To determine the association between baseball specific training load (arm-specific and body-specific 4-week cumulative sRPE and ACWR) and percent change from baseline of objective fatigue measures (countermovement jump height and power and grip strength) in collegiate baseball players.

Hypothesis 2: There will be a negative relationship between baseball specific training load and objective fatigue measures percent change from baseline. This indicates that athletes with high cumulative total loads and high ACWR will demonstrate decreased performance in the countermovement jump (decreased jump height and power) and the grip strength assessment (decreased peak grip strength).

Specific Aim 3

To determine the association between baseball specific training load (arm-specific and body-specific 4-week cumulative sRPE and ACWR) and subjective well-being measures (1-week averages of self-reported readiness, self-reported fatigue, self-reported soreness, self-reported stress) in collegiate baseball players.

Hypothesis 3: There will be a negative relationship between baseball specific training load and subjective well-being measures. This indicates that athletes with high cumulative loads and high ACWR will demonstrate lower readiness to participate, self-reported fatigue, self-reported soreness, and self-reported stress.

Specific Aim 4

To determine the association between baseball specific training load (arm-specific and body-specific 4-week cumulative sRPE and ACWR) and percent change from baseline in baseball performance measures (weekly average fastball speed, weekly average fastball spin, and weekly average exit velocity on balls hit in the field of play) in collegiate baseball participants.

Hypothesis 4: There will be a negative relationship between baseball specific training load and baseball performance measures. This indicates that athletes with high cumulative loads and high ACWR, will demonstrate outcomes associated with poor performance (negative change in fastball speed, negative change in fastball spin, and negative change in exit velocity on balls hit in the field of play).

Independent Variables

Specific Aim 1 and 2

- Arm-specific ACWR

- Body-specific ACWR

- Arm-specific cumulative sRPE

- Body-specific cumulative sRPE

- Limb

- Subject ID (random intercept)

- Team (random intercept)

- Time (random intercept)

- Arm-specific ACWR

- Body-specific ACWR

- Arm-specific cumulative sRPE

- Body-specific cumulative sRPE

- Time

- Subject ID (random intercept)

- Team (random intercept)

Dependent Variables

Specific Aim 1

- Total rotation range of motion percent change

- Overhead reach test percent change

- Behind the back reach test percent change

- Internal rotation peak force percent change

- External rotation peak force percent change

- Single leg bridge repetitions percent change

Specific Aim 2

- Countermovement jump height percent change

- Countermovement jump power percent change

- Peak grip force percent change

Specific Aim 3

- 1-week average self-reported readiness

- 1-week average self-reported fatigue

- 1-week average self-reported soreness

- 1-week average self-reported stress

Specific Aim 4

- Weekly average fastball speed percent change

- Weekly average fastball spin percent change

- Weekly average exit velocity on balls hit in the field of play percent change

Delimitations

Only highly competitive collegiate baseball players were included.

Assumptions

- Participants answered truthfully and honestly to the training load and readiness questionnaire, which will record the daily training load measures and self-reported well-being measures.

- Participants gave maximal effort for all strength assessments and objective fatigue measure

- Load collected on the training load survey accurately represents baseball-specific load currently being performed and well-being measures accurately assess subjective well-being of the athlete

CHAPTER 2: LITERATURE REVIEW

Baseball popularity continues to increase, as sport participation has risen in amateur athletes over the past 6 years.[2] With over 15.64 million participants age 6 and up,[83] 484,000 participants in the National Federation of State High School Associations,[2] and 36,000 participants in the National Collegiate Athletic Association,[1] baseball is one of the top 3 most popular male sports at the youth, high school, and collegiate populations. Despite a growing body of evidence identifying baseball specific injury risk factors, a significant amount of time-loss injuries are still present in these athletes.[5,9,10,84] Additionally, position statements and participation guidelines specifically recommend participation parameters in baseball to reduce the incidence of injury.[85–88] The recommendations led to the development of USA Baseball's PitchSmart Guidelines, which aims to limit injury risk through age prescribed guidelines to participation and rest. It is important to identify the relationship between participation habits and potential injury risk mechanisms in baseball players to understand how injuries develop as a result of excessive play or limited recovery. This literature review will discuss current baseball epidemiology, common injuries that affect baseball players, and the sport demands of baseball. Injury risk factors of throwing injuries will be discussed, and finally, training load assessments will be presented to discuss how they may be able to quantify baseball participation.

Baseball Epidemiology

Baseball is a non-contact sport leading to low frequency of injuries, but a high prevalence of time-loss injuries. Injury rates in baseball range from 0.7 – 3.61 injuries per 1000 athlete exposures[9,89–91] or 1.79 injuries per 10 games.[8] Baseball's unique sport demands create a higher frequency of injuries in the upper extremity,[8–11] with pitchers at a higher risk of upper extremity injury than their position-playing counterparts.[6,7,10,11,90,92] Despite the low frequency of overall injury compared to other sports, many of these injuries are considered severe and require extended time lost from sport.[7,9,10] Injuries such as ulnar collateral ligament tears at the elbow and labral tears at the shoulder require surgical intervention, requiring between 13 and 20 months removed from sport.[93,94] Non-surgical injuries still create significant time loss in sport, as recent evidence suggests that an average injury in baseball causes between 16-24 days missed per injured player.[10,11] Baseball schedules are often created with limited days between games, resulting in significant amount of missed playing time due to injury. In Major League Baseball, the average season long cost of replacing injured players was over 420 million dollars.[5] Although evidence suggests a higher amount of upper extremity injuries, the burden of core and lower extremity injuries should not be ignored. Up to 25% of pitcher injuries and 60% of position player injuries affect the core or lower extremity.[9] Hamstring strains are currently the most common injury in baseball players.[11] Other common baseball injuries to the lower extremity are abdominal strains, oblique injuries, and hip/groin pathology.[9,11]

There is also a high prevalence of pain during a competitive baseball season. During a competitive year, between 25 – 74% of pitchers experience pain at the

shoulder or the elbow during throwing.[55,56,59,60,95,96] In addition, 80% of all pitchers

indicate that they experience feeling pain in their throwing arm on the day after

throwing,[6] which is likely a severe sensation of muscular soreness. Significant soreness

could be present in muscles for up to 3 days following activity.[34,58] Soreness could be

linked to changes of intramuscular composition, as increased muscle volume could

compress nociceptors and cause increased sensations of pain and pressure.[97]

Soreness is a key symptom of muscle damage and should be considered a main

outcome when assessing muscle fatigue and damage.[34,58,98] Erickson et al.[33]

demonstrates that symptoms of pain and soreness also increase as pitch count

increases, indicating a link between the two that may provide information about the

presence of muscle damage and fatigue in baseball players. Evidence suggests that

significant microtrauma may result from cumulative throwing, causing high reports of

pain and soreness consistent with muscle damage studies.[6,33] The mismanagement of

the repetitive microtrauma, either from high frequency of participation or lack of recovery

following participation, is likely to contribute to upper extremity injury.[86,87,99]

Common Injuries and Etiology

Baseball injuries often affect the upper extremity due the high joint loads at the

shoulder and elbow during the throwing motion. The upper extremity is placed under

tremendous forces during throwing that often exceed physiologic limits of non-

contractile tissue.[27] The dynamic contribution of the forearm and rotator cuff are crucial

to maintain stability and function during overhead throwing at the elbow and shoulder,

respectively.[100–103] Fatigue of these muscles transfers significant stress to non-

contractile tissue, creating changes to the structure or function of the tissue, and likely leading to injury.[27,102,103] It is important to consider common injuries at during baseball to assist in identifying how to prevent injury in this population.

Injuries to the Elbow

The elbow is a primary location of pain and injury in baseball players, with up to 47% of athletes reporting pain in their elbow during a competitive season.[55,95,96] Elbow injury requires significant time lost, as ulnar collateral ligament tears can require beyond 9 months for recovery.[104] The ulnar collateral ligament is the primary non-contractile structure that resists valgus stress.[27] The valgus stress on the elbow during pitching is very high, spiking between 60-95Nm during the late-cocking phase of throwing.[19,20,105] This is problematic for ulnar collateral ligament (UCL), as the maximal valgus stress that it can withhold is approximately 36Nm.[106] The difference between these two forces is hypothesized to develop from the wrist and finger flexor muscle group, as they provide a dynamic internal varus torque to counteract the external valgus torque during pitching.[101–103,107] The repetitive nature of throwing may fatigue this muscle group, leading to decreased force producing capability and leading to higher stress on the UCL.[27,108] The forearm flexor group is also at risk for muscle tightness and strains,[109,110] which could require time lost from sport. Recent evidence suggests that the average amount of time spent on the disabled list for professional pitchers with an injury labeled forearm flexor strain was 100 days.[110] Additionally, Hodgins et al.[110] demonstrated that a higher proportion of athletes with a previous forearm flexor strain went on to receive a UCL reconstruction during their playing career than athletes without a previous forearm flexor strain. In youth and adolescent baseball players, the stress and forces of pitching

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are likely to affect the growth plates of the arm,[109] likely resulting in a change in humeral

torsion over the career of the young athlete.[111,112] Excessive throwing can irritate the

medial physis; high amounts of tension at the medial elbow during pitching in addition to

the forearm muscle activity can lead to significant irritation at the medial epicondylar

growth plate, leading to a diagnosis of little league elbow.[113]

Injuries to the Shoulder

Labral tears are not uncommon in baseball players, as the glenohumeral joint

moves through extreme ranges of motion during throwing. One of the more common

shoulder labral injuries is a superior labral tear, anterior to posterior, commonly called a

SLAP tear.[95] These injuries occur at the insertion point of the biceps tendon via the

superior glenoid labrum onto the superior glenoid tubercle.[50] The biceps tendon is

maximally wound during the late cocking and acceleration phase due to the external

rotation occurring at the glenohumeral joint. Twisting of the biceps tendon causes

significant shearing forces to occur at the bone-labrum interface.[50,114] The twisting of the

biceps and associated shear stresses at the bone is termed the peel-back

mechanism.[50] The repetitive throwing motion causes significant tensile stress to the

anterior joint capsule from the humeral head creating a cam effect. The repetitive stress

is theorized to lead to anterior capsule stretching and increased external rotation.[114]

Excessive external rotation could increase the shear stresses at the biceps-labral

complex, increasing risk of injury of a superior labral (SLAP) tear.[114] Previous evidence

suggests that those with previous SLAP tear may have altered pitching mechanics to

prevent such high loads at the biceps-labral complex. Pitchers with previous SLAP tear

pitch with less external rotation and a more upright trunk.[22] The lack of external rotation

during throwing may be a protective mechanism of the biceps-labral complex, as increased amounts of external rotation may lead to increased winding and shear stresses about the biceps-labral complex.[50,114]

Subacromial and internal impingement can occur in overhead throwers due to the soft tissue changes that result from throwing.[47,115–117] Subacromial impingement is the pinching of structures beneath the acromial arch and the coracoacromial ligament.[118] Repeated throwing causes thickening of the posterior joint capsule, causing the humeral head to rise in the glenoid cavity.[50,114] This repositioning reduces the distance of the subacromial space, possibly compressing the structures below the acromial arch.[118] The compression of the contents in the subacromial space may lead to increased inflammation and swelling, further decreasing the amount of space within this already small area.[119] Altered scapular kinematics are also implicated in subacromial impingement, as evidence suggests that scapular kinematics during functional movements are altered in those with subacromial impingement.[120,121] Posterior joint capsule contracture can also lead to internal impingement. Baseball players diagnosed with internal impingement present with posterior shoulder tightness, as indicated by decreased horizontal adduction and internal rotation range of motion.[47] Internal impingement presents with pain in the posterior shoulder, especially during terminal external rotation of the shoulder, as this is the when the posterior joint capsule is pinched between the posterior glenoid rim and greater tubercle of the humerus.[50,118]

Injuries to the Lower Extremity

While baseball injuries are most common in the upper extremity, it is important to note that there is still a high burden of core[10,122] and lower extremity injury,[10,11,89] with

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the most common in professional baseball being hamstring strains.[11] Pitchers are more

likely to sustain shoulder and elbow injuries due to the amount of throwing,[5,123] but

position players are more likely to sustain injuries to the lower extremity and core.[9]

Hamstring strains often develop from running mechanisms,[124] an action that is inherent

to baseball position players due to the demands of fielding and hitting. Previous

evidence suggests that hamstring strength is related to hamstring strain incidence.[124–126] Specifically, low eccentric hamstring strength is indicative of higher risk of hamstring

injury.[127] Previous evidence indicates that clinical measures of strength, such as the

single leg bridge test, may identify those at risk for injury.[125] Monitoring hamstring

strength longitudinally may provide information regarding injury risk development in

baseball position players, but may also provide an indication of lower extremity strength

in baseball pitchers. The lower extremity is vital to the throwing motion, so monitoring

lower extremity strength, either via specific strength testing or clinically feasible test

such as the single leg bridge test and countermovement jump (CMJ), could provide

information about fatigue state in the hamstring group.

The abdominal muscle group is also an area of injury for baseball players.[122]

Abdominal oblique injuries are still a significant source of time-loss injuries in both

pitchers and hitters, with the average injury requiring over 22 days removed from

sport.[128] Abdominal muscle injuries demonstrated a significant upward trend from the

1990s to 2010,[122] but recent evidence suggests that abdominal injuries have leveled out

in recent years.[128] The vast majority of these injuries occur to the contralateral side of

the dominant arm and their dominant hitting side.[122] Hitting and pitching were

considered the primary mechanism of injury for these injuries,[122] where a very quick

explosive movement occurs in a rotational manner.[129] Abdominal injuries are also most likely to occur within the first month of the season.[122] Nealon et al.[129] suggests that the overall deconditioning from the off-season and subsequent increase in activity intensity could be a contributing factor to abdominal oblique muscle injuries. Training load monitoring could provide a means to appropriately prescribe exercise to ensure that large increases in load do not occur, and therefore do not increase the injury risk of abdominal muscle injuries.

Sport Demands of Baseball

The baseball throwing motion is one of the fastest human movements ever recorded.[130] Although often thought of as upper extremity oriented, the throwing motion is a total body movement[131,132] that utilizes the summation of speed principle to maximize performance. The summation of speed principle indicates that to maximize speed in the body, the distal segment should initiate movement when the proximal segment is at its peak velocity.[14,133] This specific sequencing allows the subsequent segment to receive the potential and kinetic energy that was generated by the previous segment.[130] Incorrect sequencing or poor facilitation of this sequence may cause improper timing and higher joint loads,[15,16,130–132,134,135] potentially leading to injury.[136] The pitching motion creates very high joint angular velocities,[19,20] leading to very high joint loads.[137,138] The high joint loads require significant muscular activity to stabilize the shoulder and elbow during the throwing motion.[23,139] Insufficient force production, potentially from a fatigued state, could lead to a higher amount of load on the non-contractile soft tissue, such as the glenoid labrum[139] or the ulnar collateral ligament,[27]

two commonly injured soft tissue structures at the shoulder and elbow. It is important to highlight the throwing motion as a potential mechanism of injury in baseball players.

The throwing motion can be broken down into 6 phases: wind-up, stride, cocking, acceleration, deceleration and follow-through.[21,135] The wind-up and stride phases utilize very strong lower extremity muscles to create force at the lower extremity that will be transferred through the core and into the upper extremity.[16,131] As the foot strides forward, the hip abductors push the body forward and move the body linearly towards the throwing target.[130,140] As the front foot hits the ground, the ground reaction force moves up the lower extremity to begin hip rotation during the cocking phase.[141] This ground reaction force under the stride leg better predicts throwing velocity,[131] indicating the lower extremity's contribution to throwing is more than just creating a linear momentum towards home plate. After hip rotation, the upper torso begins to rotate,[16] following by external rotation of the glenohumeral joint. During baseball pitching, the upper arm can externally rotate up to 180 degrees.[15,16,142] At the late-cocking and early acceleration phase, the elbow valgus torque peaks up to 99 Nm.[19,138,142] This torque is counteracted by the ulnar collateral ligament (UCL) and the bony congruency of the elbow, but a significant amount of internal varus torque is provided by the medial forearm muscles, primarily the wrist and finger flexors.[102,103,108] Fatigue of these muscles could potentially place higher amount of stress on the UCL,[27,102] leading to failure. The acceleration phase requires significant muscle activity of the rotator cuff to stabilize the humeral head during the high speed movement at the shoulder and elbow.[23,139] Joint angular velocities are the highest during this phase, with the shoulder

internally rotating at speeds up to 7500 degrees per second at the shoulder[19,20] and 3200 degrees per second at the elbow.[19]

Ball release marks the end of the acceleration phase and the body moves into the deceleration phase. This is a critical part of the throwing motion,[140] where the body must move from a concentric force producing action to an eccentric force dissipating action. The shoulder proximal load peaks during this phase, with joints loads up to 1.2 times body weight,[16] or 1080 N.[140] The rotator cuff, especially the infraspinatus, is highly eccentrically active to counteract the high shoulder proximal force.[23] The repeated eccentric nature of baseball pitching causes significant trauma to the glenohumeral joint, leading to changes in glenohumeral internal rotation,[28–30,143] shoulder strength,[144] and rotator cuff muscle size.[28,32,51] These changes are similar to those seen in muscle damage and fatigue studies, where evidence demonstrates significant changes to the musculoskeletal system, including decreased force production,[34–36,58,98,145–147] change in range of motion,[34,58,148–150] and change in muscle size[36,145,146,150–152] and quality.[34,36,58] The high velocity eccentric contraction paired with the repetitiveness of baseball throwing is theorized to cause significant muscle disruption and fatigue to the posterior shoulder. Consistent baseball throwing leads to changes in the posterior shoulder and the upper extremity, as indicated by a change in posterior capsule thickness[153] and increased humeral torsion about the arm.[154]

It is important to consider throwing load experienced by fielders, despite the lower overall volume. Evidence suggests that there is no significant difference in joint loads between a fastball pitch and throws of 18, 27, 37, and 55 meters long.[138] Throws of up to 88 meters demonstrate higher joint loads on the elbow than a maximum effort

fast ball pitch.[19] Instead, joint loads are more related to the effort of throwing, as higher effort throws lead to higher humeral internal rotation torque and normalized elbow valgus torque.[138] The number of throws and the exertion of those throws are very important to monitor, as they may contribute to upper extremity joint loads and changes that occur due to those loads.

Intrinsic Injury Risk Factors and Risk Factor Development

Baseball specific injury risk factors have previously been identified in cross sectional, longitudinal, and prospective studies. Intrinsic injury risk factors, physical characteristics of the individual, likely develop as a product of the sport demands and the extrinsic risk factors, variables external to the individual. When a baseball player participates in sport, muscular trauma and stress occurs as a result of standard participation and requires recovery before a subsequent bout. It is important to discuss intrinsic risk factors and how they develop to demonstrate the need for longitudinal assessments and activity tracking. The primary intrinsic injury risk factors are altered range of motion and decreased glenohumeral strength.

<u>Altered Range of Motion</u>

Previous evidence suggests that baseball players demonstrate significantly less internal rotation and horizontal adduction range of motion in their dominant arm when compared to their non-dominant arm[37,40,155–157] and significantly more external rotation on the dominant arm when compared to the non-dominant arm.[40,156] Baseball pitching places the glenohumeral joint at extreme terminal ranges of motion, especially during the late cocking and acceleration phases.[21,52] When paired with the high joint loads and

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significant muscular demand,[23,158] significant changes to the glenohumeral range of motion can occur following a single bout of activity[28,29,143] as well as longitudinally over the course of a season.[159,160] Excessive external rotation during the late cocking and acceleration phase leads to anterior joint capsule laxity,[50] and the deceleration phase's high eccentric activity causes thickening to the posterior capsule.[50,161] Thickened posterior capsule corresponds with decreased internal rotation and decreased horizontal adduction.[161]

Additionally, baseball players demonstrate significantly different range of motion in their dominant arm compared to the non-dominant arm.[37,40,155–157] The decreased internal rotation on the dominant arm compared to the non-dominant arm is termed glenohumeral internal rotation deficit (GIRD).[37,40,50,162] Prospective studies indicate that GIRD is a risk factor for injury,[46,163] and baseball players with internal impingement and UCL tears demonstrate significantly more GIRD than healthy controls.[45,47,164] Baseball players also demonstrate a significantly higher amount of external rotation in their dominant arm, termed external rotation gain (ERG).[40,156] Decreased external rotation has been identified as a significant injury risk factor for shoulder injuries in prospective studies.[37] Additionally, baseball players with a UCL tear demonstrate significantly lower external rotation when compared to healthy players.[38] While internal and external rotation independently might assist in predicting injury, the combination of the two may be more predictive of injury. The sum of internal and external rotation range of motion is the total rotational range of motion (TROM).[37,40] Deficits in TROM side-to-side place baseball players at higher risk of injury,[39,40,44] and players with injury demonstrate decreased TROM in their dominant arms when compared to healthy controls.[38,45] What

is most interesting about these studies is that TROM deficits have been linked to injury at the shoulder[39] and at the elbow,[38,45] indicating that significant changes in glenohumeral TROM could have injurious effects at joints further down the chain. Assessing TROM also accounts for potential changes in bony adaptation that resulted from throwing. Humeral retrotorsion is significantly higher in the dominant limb of throwing athletes, and can influence the interpretation of range of motion measures.[48] When using TROM, humeral torsion is accounted for in both the internal and external rotation range of motion, and therefore does not need to be measured to ascertain an accurate rotational range of motion measurement. [48] Finally, previous evidence suggests that humeral torsion does not change over the course of the year in high school baseball players,[112] but range of motion does change over the course of a season.[112,159,165] Since humeral torsion is unlikely to change over the course of the season or in skeletally mature individuals, changes due to excessive throwing are likely due to soft tissue changes and not bony adaptations.

Range of motion changes occur due to activities that cause muscle stress, such as baseball throwing and participation. In laboratory controlled studies, there is a significant change when repeated eccentric actions are performed, but not concentric actions.[144] Repeated eccentric actions cause a decrease in optimum angle, indicating a decrease in range of motion and a change in the angle of motion that creates peak torque during strength assessment.[34] At the shoulder, repeated eccentric motions that attempted to mimic baseball pitching demonstrated a 13% decrease in glenohumeral internal rotation range of motion.[150]

Outside of the laboratory, there is significant evidence to suggest that there is a change in range of motion following sport participation. With regards to glenohumeral internal rotation range of motion, multiple studies have found a significant decrease in internal rotation range of motion immediately following and on the days following pitching.[29,30,159,165,166] Kibler et al.[143] and Reuther et al.[30] demonstrated that internal rotation both decreased for up to 3 days following baseball pitching. The deceleration phase of throwing, where the posterior rotator cuff is highly eccentrically active to provide joint compression of the upper extremity, places high joint forces on the posterior soft tissue of the shoulder.[28,150] This stress may cause muscle tightness of the infraspinatus and teres minor, which will limit the amount of internal rotation in the following days. Additional baseball participation prior to full recovery may exacerbate the changes leading to an internal rotation range of motion decrease that could increase the risk of injury.[28] In glenohumeral external rotation and total rotation range of motion, evidence suggests that there is a significant increase immediately following baseball pitching.[28,33,165,166] These changes likely stem from the repeated stress of the layback position. The late cocking and early acceleration phases of pitching test the joint capsule to its end ranges of motion. The stress of maximum external rotation winds the joint capsule as the humeral head creates a cam effect and stresses the anterior portion of the joint capsule.[50,114] The repeated motions of baseball pitching may continually stress the anterior joint capsule, leading to more external rotation.

Strength Deficits

The sport demands of baseball require significant activation of the upper extremity muscles during baseball pitching.[23,158] The repeated nature and high effort

level results in significant muscle stress and fatigue. Muscles lose the ability to produce force and produce force quickly during times when muscle fatigue is present. This is the hallmark sign of fatigue. Strength decrements following muscle fatigue protocols can be up to 30% of peak force and last for up to 10 days.[34,58] These decrements likely develop from the muscle disruption of eccentric muscle action,[34,167] similar to the posterior shoulder's action during deceleration. Previous evidence suggests that higher rates of eccentric muscle activity lead to higher changes in strength and creatine kinase levels following eccentric activity.[35] The high velocity of baseball throwing's eccentric contraction paired with the repetitiveness of the throwing motion is theorized to cause significant muscle disruption and fatigue to the posterior shoulder during baseball throwing.

There is a significant decrease in internal rotation strength, shoulder abduction and shoulder adduction following baseball pitching.[31] Evidence also suggests that there is significant external rotation and internal rotation work fatigue, indicating that these muscles produce less force in repeated contractions from pregame to postgame.[168] There is limited evidence to suggest how long strength decrements last. Significant strength losses following baseball participation indicate muscular fatigue is present, and potentially lead to a lack of stability in the shoulder joint. Decreased muscular force in the shoulder has previously been linked to excessive laxity.[139] When the rotator cuff was resected in cadaveric models, there was a significant increase in soft tissue stress at the anterior shoulder.[139] A decrease in the force producing capability of the shoulder may lead to significantly more translation in the joint, and ultimately more joint forces being translated to non-contractile soft tissue.

Changes that occur as a result of activity could affect injury risk, as improper recovery could lead to continual strength changes. Overall, baseball players demonstrate significant differences in muscle strength side-to-side at the glenohumeral and scapulothoracic joints.[169–171] Baseball players demonstrate significantly higher peak torque and total work of the dominant arm internal rotators when compared to the non-dominant internal rotators.[43,155,156,172] When comparing scapular stabilizing muscles, the dominant middle trapezius and lower trapezius demonstrate significantly higher peak torque on the dominant arm.[43,156] There is conflicting evidence regarding strength in the external rotator group, with some evidence to suggest that external rotation demonstrates lower peak torque in the dominant limb[156,173] and other research suggesting higher peak torque in the dominant limb.[43] These muscles are primarily responsible for the deceleration of the arm following ball release[23,28,174] and significantly contribute to glenohumeral stability.[139] A lack of control during the deceleration phase may lead to stress being placed on non-contractile tissue not used to high joint loading, as previous evidence indicates that a decrease in infraspinatus activity could lead to a loss in rotator cuff compression force.[139] Lack of strength and/or low rate of force development could be detrimental for shoulder and elbow health. Evidence suggests that throwing arm internal and external rotation strength is significantly lower in the dominant arm of injured pitchers when compared to healthy controls.[164] Preseason external rotation strength weakness could be predictive of injury, as pitchers with preseason external rotation weakness demonstrate higher rates of injury.[41,44]

Recent evidence has attempted to identify how strength responds to different loads throughout the year. McHugh et al.[155] demonstrated that dominant arm

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supraspinatus strength was affected by total pitch volume during the season, with high volume pitchers demonstrating larger losses in peak force. External rotation and internal rotation decreased over the course of the season as well but was not affected by volume. This study demonstrates the importance of quantifying load throughout an athletic calendar year to assist in identifying potentially pathologic changes. This study failed to account for non-competitive throws and a measure of perceived exertion, which could provide more evidence to indicate how strength responds to the physical work and physiological response of baseball participation.

Extrinsic Risk Factors

Extrinsic risk factors are non-physical external factors that may contribute to injury in baseball players. The upper extremity may be at higher risk of fatigue and physical changes as a result of sport participation, due to its lack of use during ambulation.[34] The primary extrinsic risk factors are excessive participation, lack of rest and recovery, and self-reported fatigue. These are all intertwined, as excessive participation will lead to limited recovery time between practices and competitions. Decreased rest and recovery will lead to higher self-reported fatigue, as the body will not have enough time to repair damaged tissues which will lead to physical changes similar to intrinsic injury risk factors.

Excessive Participation

Previous evidence suggests that the amount of participation or rate of participation is associated with injury.[54–56,75] Injured baseball pitchers threw more months per year, games per year, and pitches per year than those who were

uninjured.[54,56,175] Injured pitchers also demonstrate more throws per day than uninjured pitchers.[24] With the increasing prominence of showcase baseball played outside of a high school season, research suggests that those who participate in showcase baseball are at higher risk of injury.[54,59,95] Participating on multiple teams also increases the risk of injury, which is consistent with the prevalence of showcase baseball.[6,59,95]

While excessive pitching has previously demonstrated to be related to injury, some evidence also suggests that too little pitching is related to injury as well. Lyman et al.[55] demonstrated that baseball pitchers who throw over 600 pitches in one year are at a higher risk of injury, and pitchers that threw under 300 pitches per year were at higher risk of injury. Pitchers who throw over 600 pitches in a year may be overplaying, as cumulative loads could overload the tissue to the point of injury. Pitchers who throw under 300 pitches per year may not have enough arm fitness to deal with standard pitching loads. This study highlights that excessive baseball participation is related to injury risk, but a lack of preparation and training may also be related to injury. It is important to track the amount of play that is taking place, but also the amount of training. Insufficient training may lead to a lack of conditioning, potentially increasing fatigue with just standard baseball participation.[63]

Insufficient Rest and Recovery

Limited recovery is problematic for baseball pitchers, as there is evidence to suggest that range of motion, [28–30,51,143] strength,[31] and self-reported pain and fatigue[33] demonstrate negative responses associated with injury following baseball pitching. Baseball participation prior to full recovery of these variables could lead to further negative changes and ultimately, injury. Limited rest and recovery may develop from too

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frequent of baseball participation. Baseball players who play on multiple teams are at higher risk of injury than those who do not play on multiple teams.[6,59,95] Participating on multiple teams increases the overall load that a baseball athlete experiences, but also interferes with recovery, as the seasons often overlap. In addition, there is literature to suggest that fewer days of rest between pitching bouts may lead to higher rates of injury.[175] With the addition of pitch count rules, required rest rules have been implemented to ensure proper amount of rest between pitching bouts.[3] While these rules were made with good meaning, many baseball pitchers play on multiple teams,[6] making these rules difficult to enforce for a single individual. The addition of a training load tool would assist in tracking proper pitching guidelines as well as when rest should occur.

Self-Reported Fatigue

Self-reported fatigue is a primary risk factor of injury in baseball.[54,56,59,60] Baseball pitchers who throw regularly with fatigue were 36 times more likely than those who did not pitch with arm fatigue.[54] Previous evidence also suggests that those who pitch with arm tiredness are at 7.78 times higher risk of pain and 3.71 times higher risk of injury than those who pitched with no arm tiredness.[60] Pitching with arm tiredness is associated with shoulder injury in high school and adolescent baseball players.[59] The presence of muscle fatigue in the shoulder may limit the ability to provide joint compression at the shoulder and elbow.[139] The loss of stability may cause higher joint forces to be transferred to the soft tissue, leading to failure of this soft tissue.[27,176] Monitoring the amount of arm fatigue is difficult, as fatigue is a multi-dimensional property that is defined in many different ways. In the aforementioned studies, all of

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these were measured with self-reported fatigue or arm tiredness. This variable should be collected in studies that aim to quantify fatigue, as it is considered a primary risk factor in baseball players.

Training Load

Athletes participate in training programs that alter frequency, duration, and intensity of exercise to enhance performance.[177] These variables could have considerable effects on injury risk in athletes.[67,178] Large changes to the duration and intensity of training may lead to negative effects and overtraining,[66,179] especially in the athlete that does not have adequate fitness developed, such as the preseason.[68,92,180] Additionally, increasing the frequency of training could lead to insufficient rest and recovery times, dampening the positive effects of training and lead to overreaching.[177] However, insufficient training reduces the opportunity for positive effects, limiting increases in performance and decreasing tissue resiliency.[66,177] Thus it is important to appropriately prescribe frequency, duration, and intensity to enhance performance while still protecting against injury.[66,177] Recent position statements indicate the importance of properly prescribing exercise training to ensure that overtraining does not occur.[85,181]

The amount of training and participation can be monitored by recording variables associated with physical work of an individual activity, but also the perception or the body's response to each activity bout.[64,182] The physical work component of training does not encompass the reaction of the body or the perception of difficulty, as the relationships between these two are low to moderate.[182] When assessing the amount of training via quantification of external application of load and the internal reaction to that

load, the subsequent total load measure better reflects the true load that the body is experiencing.[183–187] Daily total loads can then be summed to assess the cumulative load that an individual is experiencing over a given period of time.[67,188,189] While cumulative loads are associated with injury and performance, evidence indicates that large changes to training load, including increases and decreases, are also related to injury risk.[62,65] Training load variables have been linked to both injury and performance variables in sport, so there exists a need to quantify training loads in baseball players. Baseball's unique sport demands may require alternative methods to properly assess the training load in the upper and lower extremity. Evidence suggests that load monitoring is not well-developed in the upper extremity,[61] so there exists a need to find innovative and feasible tools to monitor baseball specific training load.

External Load

External load is considered the physical work component of training. This variable is often measured in duration, distance, steps, throws, strokes, jumps, or inertial measurement unit data.[177] Literature suggests that external load is associated with injury.[67,190–193] When comparing injured to non-injured players, evidence suggests that injured players reported significantly higher duration over the preceding week.[191] Additionally, weekly duration was significantly higher for ill players when compared to healthy players.[192] When using inertial measurement units and global positioning data, there is evidence that suggests those who run at a very high speed of over 9 meters per session are at 2.7 times more likely to get injured than those who do not.[191] Colby et al.[67] demonstrated that when averaged over the course of 3 weeks, high total distance was found to be associated with greater injury risk when compared to lower distances.

Additionally, Colby demonstrated that a low 3-weekly sprint distance was associated with injury, suggesting that it may be a balance of overtraining and undertraining that contributes to injury.[67] Specifically in overhead athletes, evidence suggests that external training loads have a relationship with upper extremity injury. Cricket bowlers with a high weekly training loads were at increased risk of injury when they performed over 203 deliveries per week.[194] Hulin et al.[65] examined cricket athletes, and demonstrated that those with high external training loads, measured in overs (throwing term in cricket), are associated with lower injury rates. Conflicting evidence suggests that when fast bowlers bowled more than 50 match overs in a 5 day period, there were at a 1.5 times higher risk of injury over the following month.[72] These authors suggest that there is significant extended delay between high training loads and increased risk of injury in overhead athletes, suggesting that external training loads should be summed over the course of 4 weeks to understand the influence of high external loads on injury risk.[71,72] It is interesting to note that both high and low external training loads are associated with injury in athletic populations.

Throw count can be considered external training load, as it is the physical work performed by a baseball athlete. Previous evidence suggests that pitch count is associated with injury, [54–56,60,75] as high pitch counts, high innings count, and throwing more months per year are retrospectively associated with pitching-related injury in the upper extremity.[54] Additionally, Lyman et al.[56] demonstrated that those who pitch between 300-600 pitches per year are less likely to get injured than those who pitch outside of that range. Lyman suggests that those who throw over 600 pitches are likely participating too much and overloading tissue at the shoulder and elbow, leading to

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injury. The authors go on to state that those who throw under 300 pitches are likely undertrained and have not developed the fitness to deal with a subsequent throwing bout. These conclusions fit with previous evidence that suggests both insufficient and excessive training could lead to injury.[62,66] Physical characteristics may also be related to excessive training load. McHugh et al.[155] indicates that shoulder strength demonstrates significant decreases when baseball pitchers throw over 400 pitches in a single season. External training loads demonstrate a consistent effect on injury risk and previously identified upper extremity injury risk factors. Unfortunately, recent evidence suggests that the reported external loads may not be the true load that baseball player's experience. Zaremski et al.[195] demonstrated that live game pitches only account for 57% of all throws made in any one game during a high school season. Warm-up throws, bullpen throws, and throws made between innings can all contribute to the overall throw count experienced by a pitcher. The total amount of throws may be even higher, as this study did not account for any throws before bullpen pitches. Warm-up throws, such as long toss or flat ground throwing, may be equally as taxing on the arm as throwing off a mound,[19,20,196] so it is important to quantify non-game throws along with in-game pitches. Additionally, this study failed to recognize throws from position players. While they experience injury at a lower rate than their pitching counterparts, upper extremity injuries are still present in position players.

Internal Load and Total Load

Internal load is the quantification of physiological response to exercise or the perception of difficulty of exercise. Internal load is often recorded in heart rate variables, ventilatory threshold (VO2), training impulse, biomarkers such as blood lactate and

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creatine kinase, and rating of perceived exertion (RPE).[197] Although there is a subjective nature to the measure, RPE was found to be a valid assessment of internal load when compared to blood lactate and heart rate.[183,198,199] Foster et al. [64] further established the utility of RPE when recorded with duration of activity to create a measure termed session RPE (sRPE). This measure demonstrated significant association with Edwards and Bannister's training impulse and average heart rate to measure training load during activity.[64,186]

The use of sRPE has become very common in recent research studies due to its ease of collection and its association with injury.[182] Evidence suggests that there is a general positive correlation between total weekly load and injury,[200] with high weekly averages being associated with higher risk of injury.[74,178,198,201,202] Malone et al.[74] demonstrated that individuals with high sRPE averaged over 1 week, 2 weeks, and 3 weeks were at a significantly higher injury risk than those with lower sRPE over those same time periods. The incidence of training injuries and match injuries are also associated with sRPE in sports such as soccer. Measures of internal load using the sRPE have yet to be used in baseball players, but there is evidence to suggest that it could be utilized to assess training load. Baseball players demonstrate a significant change to markers of internal load following sport participation. Previous evidence suggests that baseball players demonstrate an increase in blood biomarkers[76,77] and heart rate following activity.[203] When combined with external load measures already linked to injury, [54–56,60,75] assessments of cumulative sRPE could provide significant utility to determine how baseball players respond to training.

Acute to Chronic Workload Ratio

Acute to Chronic Workload Ratio (ACWR) is a representative score of the most recent training against the amount of training that the participant has been performing over an extended period of time.[63,204] A major benefit of the ACWR is that it can be modeled using measures of both internal and external loads. Acute loads are the short term quantification of training, and are designed to reflect the short term fatigue that an athlete may be experiencing.[63] Chronic loads are derived over weeks or months, and reflect the fitness that the athlete has developed.[63] Athletes develop fitness over time to increase tissue resiliency and provide a protective mechanism for the upcoming training bouts.[66] A high chronic workload indicates that the athlete has created sufficient fitness to better handle subsequent high training bouts. Acute to chronic workload ratios are often expressed in arbitrary units, so an ACWR equal to 1.5 indicates that the athlete is currently experiencing an acute load that 50% higher than the chronic load, or fitness, that the athlete has developed. [63] High ACWR indicates that negative changes may occur as a result of the training bout, including compromised neuromuscular control or reduced tissue resilience.[66]

Previous evidence suggests that the ACWR is associated with injury.[65,73,74,204–207] Hulin et al.[65] demonstrated that a high ACWR value was associated with increased risk of injury when using external workloads in cricket athletes. When the ACWR value was between 1.23 and 1.61 arbitrary units (AUs), injury risk increased by 2.88 times. Additionally, when the ACWR increased over 1.68 AUs, athletes were at a 5.8 times greater risk of injury.[65] Malone et al.[74] indicates that low ACWRs may also be related to

injury risk, as those with ACWRs less than 0.85 are at higher risk than when compared to those that have 1.00 – 1.25.

Subjective Athlete Reported Well-Being

Physical training can have considerable effects on subjective well-being, including mood,[208,209] psychological and emotional stress, [177,210–212] and feelings of fatigue and tiredness.[177,210] Subjective surveys, such as the Profile of Mood States[208,209] and the Recovery-Stress Questionnaire for Athletes[211–213] have been used to quantify changes from activity in these multidimensional constructs. These constructs are difficult to quantify and can be derived from many different areas. For instance, stress can refer to physiologic, psychologic, mental, and emotional stress that causes significant burden to athletes. Collectively, the symptoms can be referred to as subjective well-being, as they provide significant information regarding the mental state of an athlete.

These subjective well-being measures have demonstrated a relationship with training, injury state, and performance. Recent evidence suggests that subjective well-being variables may be more associated with increases in acute training loads and ongoing training.[210] Specifically, measures of stress and fatigue from the Recovery-Stress Questionnaire decrease following acute increases in training load.[214,215] Mood is also negatively affected by ongoing training. There is a significant increase in the fatigue-inertia subscale of the Profile of Mood States questionnaire following 2 months of swimming training.[209] Negative measures of subjective well-being are often present at times of illness and injury.[177] Physical stress and psychosocial stress may be precursors

to injury, as they were elevated prior to injury.[192] Similarly, decreased perceptions of recovery were related to the occurrence of illness.[192] Finally, performance variables are also related to well-being, as self-reported fatigue, stress, and muscle soreness accounted for 72% of the variance when predicting the change in competitive swimmer's time-trial performance.[216] Measures of stress ranked on a VAS from 1-5 were also significantly associated with higher game statistics in Australian football, indicating those with lower subjective stress demonstrated higher objective performance statistics.[217] A recent systematic review suggests that subjective self-reported measures may be better indicators of fatigue and recovery than objective measures.[210] It is important to consider subjective well-being alongside objective measures, because current research indicates that subjective and objective fatigue measures are not as correlated as originally thinks.[210] If subjective well-being assessments are able to provide additional information regarding general stress and fatigue, these assessments should be included as part of standard daily athlete monitoring.

Sleep is an important aspect to recovery, and could has significant effects on muscle performance and injury risk.[218–220] Athletes who get less than 8 hours of sleep each night are at a 1.7 times higher risk of injury compared to those who get over 8 hours.[220] Poor sleep may also influence performance measures, as evidence suggests that sleep disturbances and lack of sleep are associated with lower testosterone and poorer muscle function.[219] Low subjective sleep quality on the Recovery-Stress Questionnaire for Athletes was associated with a higher risk of injury.[211] More recent evidence echoes these findings, as sleep restriction impairs accuracy in athletic events, and sleep extension demonstrates accuracy improvement.[218] Sleep should be

monitored, as it could have significant effects on recovery following exercise and performance.

Methodology

Range of Motion

Shoulder rotational range of motion is often assessed in a supine position with the shoulder abducted to 90 degrees.[37,38,40,45,221] Internal rotation can be assessed in a side-lying or a supine testing position.[222,223] There is evidence to suggest that the side-lying position demonstrates excellent reliability,[222,223] but the side-lying position may put the arm in a more horizontally adducted position, already stressing the posterior capsule. The supine testing position is still highly reliable and puts the arm in 90 degrees of abduction and 0 degrees of horizontal adduction. This position also allows the tester to stabilize the humeral head in the glenoid cavity.[221] The type of stabilization likely matters, as previous evidence suggests that there is a significant amount of variation that may occur due to stabilization technique.[221] We have elected to use a supine testing position with direct pressure over the anterior shoulder in this study. This testing position is more consistent with previous research in upper extremity athletes, [37,38,40,45,221] and still demonstrates very high intra and interrater reliability.[223–225] Reach tests are also commonly used in clinical settings to assess functional range of motion of the glenohumeral joint.[226–229] It is common to perform overhead of behind the back reach tests to assess active glenohumeral external and internal rotation range of motion, respectively.[226] Previous evidence suggests that the behind the back reach tests are highly reliable ($ICC_{2,1} < 0.900$) and very precise (SEM<5%).[228]

Shoulder Strength

Previous research has used isokinetic dynamometers to quantify shoulder rotation strength.[168,169,172,174] While isokinetic dynamometers may be feasible to measure strength scores in a laboratory setting, their use is limited in the clinical setting because of their size, price, and skill requirements.[230] Handheld dynamometers (HHDs) have replaced isokinetic dynamometers to measure strength research outside of the laboratory, because they are portable and versatile.[31,41,230] However unlike isokinetic dynamometers, HHDs add tester bias, such as size, sex, and strength of the examiner into force and torque output scores.[230–232] A recent systematic review also suggested that due to the amount of bias introduced during force measurements with an HHD in the upper extremity, current research methods using HHDs are not reliable between or within testers.[230] This poor testing methodology warrants researchers to question the use of HHDs to measure glenohumeral strength and identify possible new ways of measuring force outputs at the shoulder for clinicians and non-laboratory based research. Recent evidence suggests that external fixation of a dynamometer may lead to more valid and reliable results.[233,234] A tension dynamometer specifically demonstrates highly reproducible results, with $ICC_{2,3} > 0.900$ and a standard error of less than 1 kg.[235] For these reasons, we elected to externally fix the dynamometer, with the goal of removing tester error.

Countermovement Jump Test

Previous evidence suggests that countermovement jump (CMJ) is related to fatigue state of the lower extremity.[78,236] Height and power from the CMJ can be assessed with various methods, including contact mats,[237] position transducer,[78]

photoelectric timing systems,[238] and a force plate.[78,238–240] The photoelectric timing

systems demonstrate high agreement with a force plate for assessing CMJ height and

power.[238] Countermovement jump testing on a force plate is considered the gold

standard for assessing jump height and power.[238] As such, this study has elected to use

the force plate and a photoelectric timing system to assess jump height and power.

Single Leg Bridge Test

The single leg bridge test aims at determining the functional capacity of the

hamstring group in terms of overall strength and fatigue resistance.[125] Evidence

suggests that there is significant change in T2 relaxation times of the hamstring muscle

group during the single leg hamstring bridge test,[241] indicating it's activation during this

test. Previous evidence has demonstrated that the single leg bridge test may be

predictive of hamstring strain injuries, as those with an injury to their hamstrings

demonstrated lower single leg bridge test scores than those without an injury.[125]

Additionally, the single leg hamstring bridge test demonstrated good intra- and inter-

tester reliability (ICC>0.77).[125]

Trackman Assessment

The Trackman baseball assessment unit is a military grade radar that can

determine multiple ball flight variables during in-game baseball participation. Pitching

variables that can be recorded are release height, release side, ball speed at release,

angle of release, spin rate, spin axis, horizontal movement, Cartesian location at home

plate, and ball speed at home plate. Hitting variables captured by the Trackman

baseball assessment unit include the exit velocity of the batted ball, exit angle of the

batted ball, spin rate of batted ball, carry distance, maximum height, and time of flight.

Of the variables listed above, previous evidence suggests that ball speed at release and exit velocity demonstrate very high agreement when compared to evaluation of the same variables recorded with high speed video.[242] The average error of pitch speed is 2.3% and the average error of hit speed is 2.8%,[242] indicating that these measures are highly reliable and valid when compared to manual tracking of the same variables.

Training Load

The sRPE method of assessing internal training load has demonstrated high agreement with previous measures of training impulse.[185,187,243] While it is a more basic assessment of internal load, RPE correlates with objective internal load measures, such as heart rate and blood lactate.[199] Previous evidence suggests that sRPE is valid against Bannister's and Lucia's heart rate based training impulse calculation.[184,185] Additionally, a major benefit of the sRPE method are its clinical usefulness and its practicality. The sRPE method is cost effective, practical, and noninvasive,[177,187] while still demonstrating good test-retest reliability (ICC>0.800)[186] and good validity (r=0.80-0.83) against heart rate measures of training impulse.[185,186]

Clinical Significance

Baseball players demonstrate significant changes due to participation acutely following activity[28,30,31,33] and longitudinally as a result of activity.[159,160,165] These changes are consistent with previously identified injury risk factors, including altered range of motion and strength.[41,46,47] Baseball players require time to recover from throwing, as changes from activity could be present for up to 3 days.[28,30] Excessive baseball participation or participating with limited recovery between bouts could lead to

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further decrements to strength and range of motion, potentially leading to an injurious state. It is important to identify the relationship between the amount of participation and the changes to the intrinsic injury risk factors. Training load quantification via sRPE may be a useful tool to monitor the amount and frequency of participation. Previous evidences indicates that cumulative total load and ACWR derived from sRPE measures may be predictive of injury in soccer,[74,184,244] rugby,[178,191,245] and cricket athletes,[65,71] but there is no evidence indicating if training load is related to injury in baseball players. The development of baseball specific training load model and assessment tool would allow sports medicine professionals, strength coaches, and team coaches to provide proper throwing prescription to avoid injury and increase performance. Therefore, the purpose of this study is to understand how measures of training load influence measures of musculoskeletal injury risk variables, objective fatigue, subjective well-being, and baseball performance measures in baseball players.

CHAPTER 3: METHODS

Overview

The purpose of this research project is to determine how baseball specific

training load influences musculoskeletal injury risk variables, objective fatigue

measures, subjective well-being measures, and performance variables in baseball

players. A longitudinal repeated measures study design was employed over the course

of the fall semester in collegiate baseball teams. The fall semester began with a

competitive 6-week season, with up to 3 intrasquad scrimmages each week. Following

the competitive 6-week season is a training period designed to increase baseball

performance through strength and conditioning exercises. Active members from the

University of North Carolina and University of Mount Olive baseball teams were

recruited for participation. Participants provided daily training load and subjective well-

being measures via an online survey that was completed on a computer or smartphone

device. Additionally, all participants participated in a physical data collection session at

preseason, 4-week, 8-week, 12-week, and 16-week time points, where the

musculoskeletal injury risk variables and objective fatigue measures were collected.

During the competitive baseball season, weekly baseball performance was collected by

the baseball team and used for data analyses. The study schedule is presented in

Figure 1.

Figure 1. Research Schedule

Variables	Wk 0	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Wk 9	Wk 10	Wk 11	Wk 12	Wk 13	Wk 14	Wk 15	Wk 16
			Fall Baseball Season							**Training Period**							
Training Load	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Subjective Well-Being	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Musculoskeletal Injury Risk Variables	🟥				🟥				🟥				🟥				🟥
Objective Fatigue Tests	🟧				🟧				🟧				🟧				🟧
Performance Variables			⬜	⬜	⬜	⬜	⬜	⬜	⬜								

Population and Recruitment

Participants were recruited from two collegiate baseball teams (n=61, age=19.7 ± 1.2 years, height=185.0 ± 6.5cm, mass=90.9= ± 10.2kg) with 34 from the University of Mount Olive (Mount Olive, NC) and 27 from The University of North Carolina at Chapel Hill (Chapel Hill, NC). The participants consisted of three catchers, 20 infielders, 11 outfielders, and 27 pitchers. The 61 participants combined for 178 testing sessions over the fall semester. Participants were between the ages of 18-25 and met all inclusion criteria, which included:

- Be an active member of University of North Carolina or University of Mount Olive baseball team

- Be able to access the training load and readiness surveys via either a computer or smartphone device

- Be able to complete all study procedures without pain or discomfort

Participants were screened for any ailments that influenced outcome measures. Previous physical injuries may influence the musculoskeletal injury risk variables and

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the objective fatigue outcomes over the course of the study duration. Additionally, the subjective well-being measures include scales on stress and mood, which could exacerbate mental health disorders. Exclusion criteria included the following items:

- No current injury or pain that limits participation at the start of the study

- No injury or pain that limited activity within the last 3 months

- No previous surgery within the last year

- No self-reported mental health disorder, including but not limited to anxiety, depression, or mood disorders

Research Design

A longitudinal repeated measures design was used for the current study. Participants completed a playing and injury history form regarding their baseball experience to ensure that they meet all inclusion and exclusion criteria. Once enrolled, participants completed a physical data collection session at preseason, 4-week, 8-week, 12-week, and 16-week time points throughout the course of the 2018 fall semester to collect the musculoskeletal injury risk variables and objective fatigue outcomes. Participants also filled out daily well-being and training load surveys on a computer or smartphone device. Participants were asked at each testing session if they sustained any injuries within the last 4 weeks. There were zero reported injuries.

Procedures

Prior to all study procedures, participants were screened to ensure they met all inclusion/exclusion criteria using the demographics and injury history questionnaire. If

participants met all inclusion and exclusion criteria, they were scheduled for the

preseason physical data collection session. At the preseason physical data collection

session, participants signed University of North Carolina Institutional Review Board

approved consent forms. All physical data collection sessions included assessments of

the musculoskeletal injury risk variables and the objective fatigue outcomes, which

included glenohumeral total rotation range of motion (TROM), overhead and behind the

back functional reach, grip strength, glenohumeral internal and external rotational

strength, counter movement jump (CMJ), and single leg bridge test. Participants' age,

height, and mass were obtained at the first physical data collection session.

Demographics and Injury History

Participants were asked to fill out their playing and injury history prior to all study

procedures. The questionnaire asked about positions played, pitching history, pitch

types thrown (if pitcher), and injury history. Participants were asked to provide injury

history to their shoulder and elbow only. The injury history is attached in **Appendix 1**.

Musculoskeletal Injury Risk Variables Assessment

Glenohumeral Range of Motion

Range of motion assessments included glenohumeral internal and external

rotation range of motion and overhead and behind the back functional reach test.

Rotational range of motion assessments were measured with a digital goniometer and

the reach assessments were measured with a tape measure.

Glenohumeral rotation range of motion was assessed with the subject lying

supine with the arm abducted to 90 degrees and elbow flexed 90 degrees. A researcher

stabilized the scapula by placing a posteriorly directed force on the coracoid process,

and then the researcher rotated the shoulder until terminal internal rotation was reached. A second researcher then aligned a digital inclinometer (Saunders Group, Chaska, MN, USA) with the forearm and recorded the measure on the digital inclinometer. External rotation was then examined similarly, during passive external rotation (**Figure 2**). These assessments were performed 3 times on the dominant and non-dominant limbs. The average of these three measures were recorded as the internal rotation and external rotation variables. Internal rotation and external rotation were summed to obtain the outcome measure of TROM, measured in degrees. The TROM measure was used in the statistical analyses. Reliability and precision of TROM was determined with the intraclass correlation coefficient ($ICC_{2,k}=0.868$) and standard error of the measurement (SEM=2.5%).

Figure 2. Glenohumeral rotational range of motion assessment method.

Functional Reach Test

Functional reach tests were performed with the participant standing in an upright erect position. A tape measure ran down 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 non-test arm on the ipsilateral hip while researchers tested the opposite arm. For the behind the back reach test (BBRT), the individual was instructed to place the posterior hand at the level of their sacrum, and then slide the arm up the spine until they reached their maximal distance. Once they reached the maximal distance, researchers recorded in centimeters where their thumb was located on the tape measure. This test was performed 3 times on the dominant and non-dominant limb, and the average of these 3 measures was used in the statistical analyses. For the overhead reach test (OHRT), the participant was in the same position as the BBRT and standing in an upright and erect posture with the arm not being tested resting on the hip, and the origin of the tape measure secured to the most prominent portion of the C7 spinous process. The participant was instructed to place the hand of the test limb on their head and begin sliding their hand inferiorly down their spine until they were unable to reach any further. Once they had reached the terminal distance, researchers recorded in centimeters where their middle finger was on the tape measure (**Figure 3**). If they were unable to reach C7, the measure was recorded as negative from C7. This test was performed 3 times on the dominant and non-dominant limb, and the average of the 3 measures was used in the statistical analyses. Pilot tests were performed to obtain the test-retest reliability and precision of OHRT ($ICC_{2,k}=0.959$, SEM=10.6%) and the BBRT ($ICC_{2,k}=0.0.915$, SEM=6.1%).

Figure 3. Functional reach test assessment method. Left: Overhead Reach Test. Right: Behind the Back Reach Test

Glenohumeral Rotational Strength

Shoulder rotational strength assessments were performed using a tension load cell (TSD121C Hand Dynamometer, Biopac Systems Inc., Goleta, CA, USA), a chain, and a padded handle. Participants were asked to lie prone on a plinth with the shoulder abducted to 90 degrees and elbow flexed to 90 degrees, so the hand was pointing towards the ground. The participant's humerus laid on the plinth while the forearm hung off the table. Padded buttresses were placed anterior and posterior to the humerus to prevent any motion other than internal and external rotation. A chain was secured to a fixed object at a right angle to the participant's forearm. The other end of the chain had a handle that the participant held. The load cell was placed between the handle and the secured object (i.e. plinth arm) with a carabiner and chain. The participant pulled

against the handle and chain for 3 – 4 seconds to determine their maximum (internal and external rotation) isometric strength (**Figure 4**). Participants were given one warm-up trial and then performed up to 3 trials that were recorded. Internal and external rotation was randomized. All trials were performed in one direction, and the opposite direction was performed following completion. One minute of rest was given between each test. Rotational strength data was sampled at 2000 Hz with a Biopac acquisition system (MP150, Biopac Systems Inc., Goleta, CA, USA), and raw voltage was exported as a text file on a personal computer. Outcomes used for the statistical analyses included internal rotation and external rotation peak force (IRPF and ERPF, respectively). Forearm length was also measured to express strength in terms of torque, by multiplying force by forearm length. Pilot testing was performed to determine test-retest reliability and precision of IRPF ($ICC_{2,k}$=0.936, SEM=7.4%) and ERPF ($ICC_{2,k}$=0.935, SEM=9.8%). Previous evidence suggests that handheld dynamometers may introduce bias into testing,[230] as they are often affected by tester size, weight and gender. [231,246] External fixation of a dynamometer to assess shoulder strength has demonstrated moderate to high correlation statistics (r=0.490-0.807) with an isokinetic dynamometer.[247]

Figure 4. Glenohumeral rotation strength assessment method

Single Leg Bridge Test

The single leg bridge test was measured with methods similar to Freckleton et al.[125] Participants laid supine on the ground with their arms crossed over their chest (**Figure 5)**. The heel of the testing leg was placed on the top of a box measuring 60 cm high, and the testing limb's knee was flexed to 20 degrees. The non-test leg was flexed so that the thigh was in a vertical position at rest. The non-test leg was held stationary during the testing. Participants were told to push down through the heel to lift their bottom off the ground in a controlled steady manner, until their knee, hip, and shoulder were in a straight line. Verbal feedback was provided to ensure that the proper position was attained, and then the participant returned to the rest position. If the participant did not reach the final position or does not perform the movement in a controlled steady

manner, one warning was given to notify the participant. If the participant did not reach

the final position or did not perform the movement in a controlled steady manner a

second time, the participant stopped, and the number of repetitions was recorded.

Participants performed as many repetitions as possible until they received the second

warning. Single leg bridge repetitions were recorded as the main outcome.

Figure 5. Single Leg Bridge Test rest position (top) and ending position (bottom).

Grip Strength

Grip strength assessments were collected with a handheld compression load cell (TSD121C Hand Dynamometer, Biopac Systems Inc., Goleta, CA, USA) with methods similar to Horsley et al.[248] For the grip strength assessments, participants performed maximal grip strength trials in 3 different postures: shoulder in neutral and elbow flexed to 90 degrees, shoulder abducted to 90 degrees and elbow flexed to 90 degrees, and shoulder abducted 90 degrees, externally rotated 90 degrees and elbow flexed 90 degrees (**Figure 6**)**.** Previous evidence suggests that blood flow is correlated to grip strength in the full abducted and externally rotated position, so we elected to use 3 separate postures for this assessment.[249] Participants stood with their heels, buttocks, shoulders, head, and elbow against a wall for all the grip strength assessments. Participants were instructed to squeeze the grip dynamometer with maximum force for 3-4 seconds. Participants performed a single trial in each posture, and the average of these measures was used for data analysis. Grip strength data was sampled at 2000 Hz with a Biopac acquisition system (MP150, Biopac Systems Inc., Goleta, CA, USA), and raw voltage was exported as a text file on a personal computer. Pilot testing was performed to establish test-retest reliability ($ICC_{2,3}=0.936$) and precision (SEM=7.05%) of the grip strength assessment. Previous evidence suggests that grip strength is related to total body strength[250] and shoulder external rotation strength.[248] Additionally, muscle activation of the forearm must provide dynamic stabilization to the medial elbow, as the elbow valgus torques exceed the failure point of the UCL.[103,137,251]

Figure 6. Grip strength assessment postures

Countermovement Jump

The CMJ test was assessed using a force plate (Bertec, Columbus, OH, USA) and an optical sensor rail (Optogait, Microgate, Bolzano-Bozen, Italy) to obtain jump height and power. Participants started the CMJ while standing in an erect posture with their feet shoulder width apart and each foot on a separate force plate. The participants placed their hands on their hips to reduce the influence of the upper extremity on jump height. When the participant was ready, he squatted down and then jumped for maximum height in one fluid motion without removing the hands from the hips (**Figure 7**). Participants were given up to 3 test jumps and then performed 3 CMJ tests that were recorded. If the participant's hands came off their hips, their foot did not completely land on the force plate, or they lost their balance during landing, the trial was repeated. The forces were recorded during the jump and saved to a file for later data reduction. For participants at the University of Mount Olive, the optical sensor was used to determine flight time. Previous evidence indicates that a CMJ test is reduced following fatiguing

bouts of activity.[79] Additionally, CMJ was determined to be most repeatable and most related to neuromuscular fatigue following a sport specific fatigue protocol.[78] There is also high agreement between the optical sensor and a force plate based assessment of jump height (r^2=0.997).[238] Pilot testing was performed to determine the reliability and precision of jump height ($ICC_{2,1}$=0.969, SEM=2.2%) and power ($ICC_{2,1}$=0.996, SEM=1.5%).

Figure 7. Starting and loading position of the CMJ test.

Subjective Well-being Assessment

Subjective well-being was assessed with the Daily Baseball Readiness Survey (**Appendix 2**). This survey was developed to track daily subjective scores of well-being that may play a role in injury risk, sport performance, and training adaptations. The Daily Baseball Readiness Survey was to be completed by the participants each morning prior to activity on a computer or smartphone device (Qualtrics LLC, Provo, UT, USA). The survey consists of 8 questions and asks participants to rate their readiness to participate in sport, sleep quality, stress, mood, fatigue, and soreness on a Likert scale: readiness was rated from 0 to 100; sleep quality, fatigue, stress, and soreness was rated from -5 to +5, and mood was rated from 1 to 5 with an accompanying image. Scores closer to the minimum Likert rating recorded on the survey was associated with negative subjective measures (low readiness, poor mood, high stress, high soreness, low sleep quality, and high fatigue), and scores closer to the maximum Likert rating recorded on the survey were associated with positive subjective measures (high readiness, good mood, low stress, low soreness, high sleep quality, and low fatigue). Participants also indicated where their soreness was located. The weekly average of soreness, fatigue, and stress was used as a dependent variable in the statistical analyses.

Training Load Assessment

Training Load was recorded via the Daily Training Load Assessment Survey (**Appendix 3**). This survey was developed to feasibly and conveniently collect pertinent training variables through a computer and smartphone-based application (Qualtrics LLC, Provo, UT, USA). Participants were told to complete the Daily Training Load Assessment Survey within 30 minutes after activity each day. This survey was designed

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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 and swings that they performed during baseball participation for the day. Duration included all aspects of baseball participation, strength training, and conditioning, and this measure was recorded in minutes. Participants also provided a rating of perceived exertion (RPE) experienced during baseball participation and the current training session, recorded on a scale of 0-10, with 0 representing a resting state and 10 representing maximal exertion. The Daily Training Load Assessment Survey provided an image for participants to use as a reference to determine their level of exertion. Participants provided RPE with regards to two separate body regions: one regarding total body exertion and one regarding arm specific exertion. Participants were also asked if they performed any arm care for the day, defined as strengthening or stretching exercises specifically performed for injury prevention. Finally, a question regarding strength and conditioning was presented.

RPE was used in this study to quantify the perceived exertion during baseball related training and participation. RPE has previously shown to have high reliability and validity when compared against heart rate methods of internal load[184,199] and training impulse.[184–187] Arm specific external load was determined by throw count. All throws outside of warm-ups were to be reported in this count, including long toss, flat ground, bullpens, live games, and fielding practice. Additionally, previous evidence indicates that throws between 18 meters and 55 meters demonstrate similar joint loads.[138] Throws of over 37 meters also demonstrate joint loads that are similar to baseball pitching.[19] Due to these similar loads, all throws were equally weighted in the current study.

Baseball performance was assessed with data from a Trackman unit. TrackMan (TrackMan, Inc., Stamford, CT, USA) is a military grade radar designed to read ball flight characteristics during live baseball play. At ball release, the unit provides data on the release height (vertical position of the hand relative to the top of the pitching rubber), release extension (forward horizontal displacement from the front of the pitching rubber), and release side (lateral horizontal displacement from the middle of the pitching rubber). Following ball release during flight to home plate, the unit provides data regarding the ball velocity, ball spin rate, ball spin axis of rotation, horizontal pitch displacement due to spin, vertical pitch displacement due to spin, and vertical pitch displacement due to spin and gravity. At bat contact, the Trackman unit provides exit velocity and launch angle of the batted ball. The variables that were used in this study from the Trackman unit for baseball pitchers are percent change in weekly average fastball speed and weekly average fastball spin, and the variables used for baseball position players were percent change in weekly average exit velocity on balls hit in the field of play. Pitch speed obtained from Trackman demonstrates high agreement with pitch speed obtained from high speed video tracking, with an average error of 2.3%. Hitting velocity demonstrated equally high agreement, with the average error between Trackman and high speed video tracking to be 2.8%.[242]

Data Reduction

<u>*Glenohumeral and Grip Strength*</u>

Strength data was reduced in a custom LabView software (LabView 17.0; National Instruments, Austin, TX, USA) from text files collected during the physical data collection session. Data was filtered via a low pass filter with a cutoff frequency of 50 Hz then smoothed with a fourth order zero phase shift Butterworth filter. Following filtering, a calibration equation was used to determine the force in newtons (N) that corresponds to specific voltage outputs. This equation was created via a separate calibration session where known weights were placed on the tension dynamometer and the associated voltage outputs were recorded. A 200ms epoch was used to find the maximum average force over the duration of the trial (N). The three trials of each strength test were averaged. External rotation peak force (ERPF), internal rotation peak force (IRPF), and grip strength were used in the statistical analyses. Percent change scores were calculated as the difference between the current testing time and the most recent testing time, divided by the most recent testing time times 100 (ex: [(W8-W4)/W4]*100)

<u>*Countermovement Jump Test*</u>

The CMJ trials were downloaded as text files and then uploaded into custom software written by the primary investigator (LabView 2017, National Instruments, Austin, TX, USA). Data was smoothed with a fourth order zero phase shift Butterworth filter that is notch filtered from 59.5 – 60.5 Hz and low pass filtered at 25 Hz. Jump height was calculated by finding the flight time of the jump, considered the interval over which the vertical ground reaction force was less than 5 N. Once the flight time was calculated, the jump height was determined via the following equation: Jump height =

[flight time*9.81/2]^2/ 9.81. Jump power was calculated using the Sayer's Equation ([60.7 * Jump height (cm)] + [45.3*body mass(kg)] – 2055). Jump height was recorded in centimeters and jump power was recorded in Watts. Percent change scores were calculated as the difference between the current testing time and the most recent testing time, divided by the most recent testing time times 100 (ex: [(W8-W4)/W4]*100)

Training Load

Data from the Daily Training Load Assessment Survey was first reduced into daily total loads. Daily total body load ($sRPE_{Body}$) was calculated each day as the product of time and total body RPE, and daily arm-specific load ($sRPE_{Arm}$) was calculated each day as the product of throw count and arm-specific RPE. Four main outcome variables were calculated from the data collected on the Daily Training Load Assessment Survey: arm-specific cumulative sRPE, body-specific cumulative sRPE, arm-specific ACWR, and body-specific ACWR. To obtain the body-specific cumulative load, the $sRPE_{Body}$ for the 28 days immediately prior to the participant's physical data collection session was summed. To obtain the arm-specific cumulative sRPE, the $sRPE_{Arm}$ for the 28 days immediately prior to the participant's physical data collection session was summed. To identify large changes to $sRPE_{Body}$, the coupled body-specific ACWR was calculated as the average $sRPE_{Body}$ of the 7 days prior to the physical data collection session relative to the average $sRPE_{Body}$ of the 28 days prior to the physical data collection session. To identify large changes to $sRPE_{Arm}$, the coupled arm-specific ACWR was calculated as the average $sRPE_{Arm}$ of the 7 days prior to the physical data collection session relative to the average daily total body load of the 28 days prior to the physical data collection session. The arm-specific cumulative

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sRPE, body-specific cumulative sRPE, arm-specific ACWR, and body-specific ACWR were used as the independent variables in the statistical analyses.

Statistical Analysis

Missing Data

Missing data was handled through multiple imputation.[252–254] This method is a well-accepted within the literature and preferred over other types of imputation, such as single imputation, closest match, and standard likelihood methods.[253] Multiple imputation replaces missing values with pseudo-random values based on observed values within the dataset for a given individual.[253] After ensuring the data was missing at random or missing completely at random, the imputation procedure was performed multiple times on multiple datasets, with random error associated with each imputed data point. Research suggests that for each percent of missing data, one iteration of multiple imputation should be performed on each dataset.[254] For example, if 25% of data is missing, then 25 iterations of the multiple imputation method should be performed on each dataset. These multiple datasets can be combined to create a single complete output, on which the statistical analyses were performed. To qualify for missing data analysis, the participant was required to have at least 50% responsiveness to 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 to be drawn. Participants with under 50% could lead to inaccurate

estimates and biased imputed data. Descriptive statistics were calculated to ensure that the imputed data was within the participant's normal distribution.

Subject ID, team, date, practice type, and playing position were utilized to impute missing data for the daily sRPE$_{Arm}$ and sRPE$_{Body}$ variables. These predictor variables are hypothesized to be associated with sRPE$_{Arm}$ and sRPE$_{Body}$; for example, if an outfielder reports high training load on a specific day, it is highly likely that other outfielders on that team would also respond with high training loads for that day due to similar practice and training schedules. Once the data imputation process was completed and a single data set was extracted, arm-specific cumulative sRPE, body-specific cumulative sRPE, arm-specific ACWR, and body-specific ACWR were recalculated from the arm and body specific daily loads. The cumulative sRPE variables were rescaled to assist with interpretation of the point estimates. To better understand the parameter estimates, the 4-week cumulative body load sRPE variables were divided by 120 and 28. The outcome data point would then represent the average RPE of a two-hour training session over the last 28 days, so the parameter estimate would represent the . The 4-week cumulative arm-specific sRPE variable was divided by 25 and 28. This value would then represent the average RPE of a 25-throw training period over the last 28 days.

Statistical Analyses

Descriptive data was expressed as means and standard deviations, and confidence intervals (CI) were calculated for each parameter estimate. All analyses were performed in R software. Variables were plotted with the training load variable on

the x-axis and the dependent variable on the y-axis prior to performing the statistical analysis. Scatterplots were used to ensure that the relationship between the variables was linear. If a noticeable non-linear relationship, assessed with a local weighted scatter-plot smoothing line (LOWESS), was present between the dependent variables and fixed effects, polynomial relationships were probed to assess their significant input into the model. Additionally, the LOWESS lines were overlaid on the scatterplots to determine if there was a significant interaction between limb and fixed effect, indicated as a deviation between the dominant and non-dominant limb. The assumptions of the model creation were tested by plotting the residuals of the model against the actual values, plotting the residuals of the model to assure homogeneity of variance, assessing the normal distribution of the residuals with the Shapiro-Wilk test, and confirming the normality visually with a QQ plot.

Aim 1 was assessed with separate linear mixed models for each upper extremity range of motion and functional reach outcomes (TROM, OHRT, BBRT), upper extremity strength outcome (IRPF and ERPF), and the SLBT. The linear mixed model accounts for the variability within subjects and time and allow for the repeated measures nature of the current research study, while still using training load as an independent predictor. The arm-specific and body-specific independent variables were placed in separate models. Arm-specific 4-week cumulative sRPE and arm-specific ACWR were placed into one model, along with limb, as fixed effects. Body-specific 4-week cumulative sRPE and body-specific ACWR were placed into another model, along with limb, as fixed effects. To account for multiple entries from a single person, subject ID, time, and team

were probed as random intercepts. Variables were considered significant predictors with an alpha level of 0.05 set a priori.

Aim 2 was assessed with separate linear mixed models for each objective fatigue measure (grip strength, CMJ height, CMJ power). Objective fatigue measures' percent change from baseline served as the dependent variable. The arm-specific and body-specific independent variables were placed in separate models. Arm-specific 4-week cumulative sRPE and arm-specific ACWR were placed into one model, along with limb, as fixed effects. Body-specific 4-week cumulative sRPE and body-specific ACWR were placed into another model, along with limb, as fixed effects. To account for multiple entries from a single person, subject ID, time, and team were probed as random intercepts. Variables were considered significant predictors with an alpha level of 0.05 set a priori.

Aim 3 was assessed with separate linear mixed models for each subjective well-being measures (1-week averages of self-reported readiness, self-reported fatigue, self-reported soreness, self-reported stress). Subjective well-being measures served as the dependent variable. Arm-specific 4-week cumulative sRPE and arm-specific ACWR were placed into one model, along with time, as fixed effects. Body-specific 4-week cumulative sRPE and body-specific ACWR were placed into another model, along with time, as fixed effects. Time was recorded as the week since the start of the fall semester. Subject and team were probed as potential random effects. Data was visualized on scatterplots to assess if the relationship between the well-being variables and training load was linear or non-linear. Variables were considered significant predictors with an alpha level of 0.05 set a priori.

Aim 4 was assessed with separate linear mixed models for each baseball

performance measure (weekly average fastball release height, weekly average fastball

speed, weekly average fastball spin, weekly average fastball spin axis, and weekly

average exit velocity on balls hit in the field of play). Baseball performance measures

percent change from baseline served as the dependent variable. The arm-specific and

body-specific independent variables were placed in separate models. Arm-specific 4-

week cumulative sRPE and arm-specific ACWR were placed into one model, along with

time, as fixed effects. Body-specific 4-week cumulative sRPE and body-specific ACWR

were placed into another model, along with time, as fixed effects. To account for

multiple entries from a single person, subject ID and team were probed as random

intercepts. Variables were considered significant predictors with an alpha level of 0.05

set a priori.

CHAPTER 4: RESULTS

Demographics

<u>Data Characteristics</u>

The well-being and training load surveys were to be taken daily: the well-being prior to activity, and the training load survey following activity. Overall responsiveness of the training load and well-being surveys across the 61 participants of all possible days was poor, with response rates of 31% and 25%, respectively. To qualify for the statistical analysis, participants were required to meet all inclusion and exclusion criteria and answer at least 50% of the training load and well-being surveys from the previous 28 days. Once re-assessed with these a priori rules, the final dataset contained 18 participants that combined for 30 total physical testing sessions, and 30% of the data was imputed. For the subjective well-being variables, the dataset consisted of 19 participants that combined for 111 separate cases, and 38% of the data was imputed. For the performance variables, there were very few cases (n=14) that responded above 50%. To accommodate this, multiple imputations across the entire competitive season were used to fill in the complete dataset. Once completed, there were 34 cases from 13 pitchers, and 92 cases from 16 hitters., where 70% of the data was imputed. Physical data is presented in **Appendix 4** for each time point.

Specific Aim 1: Musculoskeletal Injury Risk Variables

<u>*Percent Change in TROM*</u>

Scatterplots did not demonstrate an apparent non-linear trend or an interaction between limbs, so linear mixed effects models were used to assess the influence of training load on TROM. While there was a positive linear trend between arm-specific ACWR and percent change in TROM (**Figure 8**), once accounting for subject, there was no significant main effect of arm-specific ACWR and cumulative sRPE on percent change in TROM and arm-specific ACWR (F=2.23, p=0.142) or cumulative sRPE (F=0.117, p=0.733). After accounting for subject as a random factor, there was no statistical significance between body-specific ACWR (F =1.08, p=0.348) or body-specific cumulative sRPE (F=0.042, p=0.958). **Table 1** contains the model parameters for all models ran for percent change in TROM.

Figure 8. Training Load and percent change in TROM by limb. Linear line of best fit is represented as the dotted black line. (A) Arm-specific ACWR, (B) Body-specific ACWR, (C) Arm-specific cumulative sRPE, (D) Body-specific cumulative sRPE.

Table 1. Model parameters from statistical analyses between percent change in TROM and training load. Upper bound and lower bound represent the 95% confidence interval of the parameter estimate.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
TROM	Linear	ID	Intercept			-2.279	2.316	-6.71	2.15
			Limb	0.2749	0.6026	-0.679	1.295	-3.15	1.8
			Arm-specific ACWR	2.2321	0.1422	2.565	1.717	-0.72	5.85
			Arm-specific Cumulative sRPE	0.1172	0.7337	0.155	0.454	-0.71	1.02
TROM	Quadratic	ID	Intercept			0.751	0.927	-0.98	2.48
			Limb	0.2749	0.6026	-0.665	1.330	-3.15	1.82
			Arm-specific ACWR	2.2321	0.1422	-0.663	5.196	-10.39	9.07
			Arm-specific Cumulative sRPE	0.1172	0.7337	-0.565	4.990	-9.91	8.78
TROM	Linear	ID	Intercept			-0.959	1.729	-2.35	4.27
			Limb	0.1831	0.6708	-0.561	1.312	-3.07	1.95
			Body-specific ACWR	0.3693	0.5464	1.308	2.153	-2.81	5.43
			Body-specific Cumulative sRPE	1.0206	0.3178	-0.261	0.258	-0.75	0.23
TROM	Quadratic	ID	Intercept			0.751	0.927	-0.98	2.48
			Limb	0.2503	0.6194	-0.665	1.329	-3.15	1.82
			Body-specific ACWR	1.0807	0.3484	-0.663	5.196	-10.39	9.06
			Body-specific Cumulative sRPE	0.0422	0.9587	-0.565	4.990	-9.91	8.77

Percent Change in External Rotation Strength

　　Scatterplots indicated a potential non-linear relationship between percent change in ERPF and body-specific cumulative sRPE (**FIGURE 9-D**), so quadratic and cubic relationships were probed between these two variables. After accounting for subject, time, and team as random effects, there was no significant relationship between percent change in ERPF and cumulative arm-specific sRPE (F=1.23, p=0.273) or arm-specific ACWR (F=0.18, p=0.668. After accounting for subject and time as random effects, there was a statistically significant cubic relationship between body-specific cumulative load and percent change in ERPF (F=3.79, p=0.022). There was no significant linear relationship between body-specific ACWR and percent change in ERPF (F=0.677, p=0.416). **Table 2** contains the model parameters for all models ran for TROM.

Figure 9. Training load and percent change in ERPF across limbs. Linear line of best fit is represented as the dotted black line. (A) Arm-specific ACWR, (B) Body-specific ACWR, (C) Arm-specific cumulative sRPE, (D) Body-specific cumulative sRPE.

Table 2. Model parameters from statistical analyses between percent change in ERPF and training load. Upper bound and lower bound represent the 95% confidence interval of the parameter estimate.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
ERPF	Linear	ID	(Intercept)			-10.217	11.076	-34.19	12.93
		Time	Limb	0.5766	0.4534	-1.636	2.155	-5.93	2.59
		Team	Arm-specific ACWR	0.1852	0.6689	1.402	3.257	-4.88	7.99
			Arm-specific Cumulative sRPE	1.2338	0.2737	1.419	1.278	-1.75	4.09
ERPF	Quadratic	ID	Intercept						
		Time	Limb	0.5668	0.4578	-1.622	2.155	-5.83	2.51
		Team	Arm-specific ACWR	0.1704	0.8439	-4.843	11.421	-26.86	19.69
			Arm-specific Cumulative sRPE	0.8348	0.441	-8.117	11.153	-29.43	13.75
ERPF	Cubic	ID	Intercept			-2.912	7.201	-19.05	13.14
		Time	Limb	0.7050	0.4082	-1.844	7.201	-6.18	2.31
		Team	Arm-specific Cumulative sRPE	1.8352	0.1594	-17.354	15.094	-45.75	-0.61
			Arm-specific ACWR	0.5481	0.6526	-21.880	11.610	-51.80	10.64
ERPF	Linear	ID	Intercept			-8.940	9.730	-29.88	11.93
		Time	Limb	0.5704	0.4557	-1.660	2.200	-6.07	2.68
		Team	Body-specific ACWR	0.6778	0.4161	2.780	3.376	-3.64	9.41
			Body-specific Cumulative sRPE	0.3144	0.5785	0.397	0.709	-1.29	1.84
ERPF	Quadratic	ID	Intercept			-4.950	8.331	-24.56	14.42
		Time	Limb	0.5726	0.4551	-1.690	2.230	66.08	2.65
		Team	Body-specific ACWR	0.7226	0.4944	5.560	13.270	-27.19	31.92
			Body-specific Cumulative sRPE	1.6969	0.1993	-18.740	10.840	-40.09	1.85
ERPF	Cubic	ID	Intercept			-3.025	3.476	-9.81	3.02
		Time	Limb	0.7600	0.39247	-2.173	2.493	-7.23	2.89
			Body-specific ACWR	0.5137	0.67703	4.217	11.590	-16.23	24.71
			Body-specific Cumulative sRPE	3.7978	0.02206	-32.331	11.485	-60.64	-11.47
								-34.19	12.93

Percent Change in Internal Rotation Strength

Scatterplots demonstrated a potential non-linear relationship between percent change in IRPF and body-specific cumulative sRPE, so quadratic and cubic mixed models were probed for this relationship (**Figure 10-D**). After accounting for subject, time, and team as random effects, there was no significant linear relationship between percent change of IRPF and arm-specific ACWR (F=0.2745, p=0.602) or arm-specific chronic sRPE (F=0.219, p=0.643). After accounting for subject, time, and team as random effects, there was a significant cubic relationship between body-specific cumulative sRPE (F=4.58, p=0.114). There was not a statistically significant linear relationship between percent change of IRPF and body-specific ACWR (F=4.00, p-=0.053). **Table 3** contains the model parameters from all models created to assess the relationship between percent change in IRPF and training load

Figure 10. Training load and percent change in IRPF across limbs. Linear line of best fit is represented as the dotted black line. (A) Arm-specific ACWR, (B) Body-specific ACWR, (C) Arm-specific cumulative sRPE, (D) Body-specific cumulative sRPE.
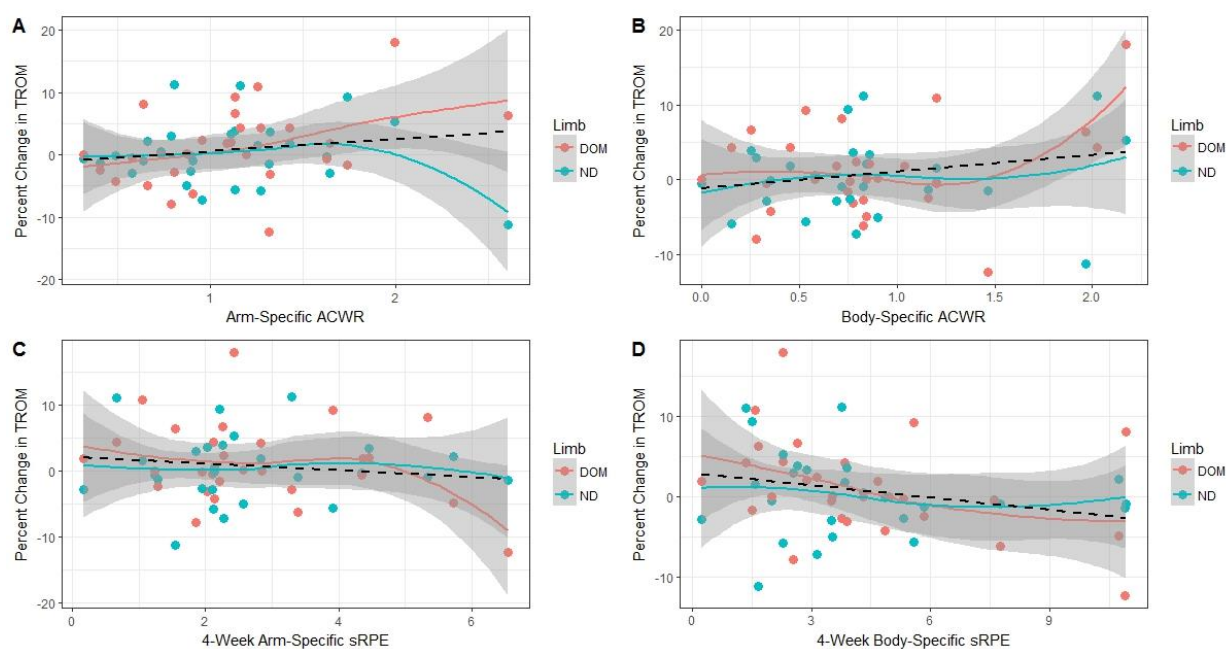

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Table 3. Model parameters from statistical analyses between percent change in IRPF and training load. Upper bound and lower bound correspond to the 95% confidence interval of the parameter estimate.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
IRPF	Linear	ID	Intercept			-2.193	10.960	-23.80	19.65
		Time	Limb	0.012	0.9721	0.127	3.608	-7.36	7.23
		Team	Arm-specific ACWR	0.274	0.6029	2.286	4.363	-5.93	11.91
			Arm-specific Cumulative sRPE	0.219	0.6433	-0.719	1.535	-3.68	2.18
IRPF	Quadratic	ID	Intercept			-1.908	9.881	-24.75	20.58
		Time*	Limb	0.005	0.9421	0.258	3.529	-6.69	7.03
		Team*	Arm-specific ACWR	3.039	0.0592	-36.336	14.973	-64.34	-6.62
			Arm-specific Cumulative sRPE	0.689	0.5115	-9.126	14.507	-35.79	22.46
IRPF	Linear	ID	Intercept			-8.201	10.252	-29.13	12.93
		Time*	Limb	0.003	0.9539	0.199	34.166	-6.74	6.91
		Team	Body-specific ACWR	4.004	0.0532	8.324	4.160	0.16	16.81
			Body-specific Cumulative sRPE	0.259	0.6143	-0.444	0.872	-2.09	1.28
IRPF	Quadratic	ID	Intercept			-2.963	9.113	-23.61	17.64
		Time*	Limb	0.005	0.9436	0.233	3.256	-6.32	6.58
		Team	Body-specific ACWR	2.987	0.0665	11.900	17.338	-25.76	46.27
			Body-specific Cumulative sRPE	1.747	0.1919	-27.406	14.807	-55.33	1.70
IRPF	Cubic	ID	Intercept			-1.745	5.371	-11.12	8.45
		Time	Limb	0.012	0.9137	-0.351	3.206	-6.82	5.91
		Team	Body-specific ACWR	2.158	0.1194	-17.919	14.097	-46.18	8.90
			Body-specific Cumulative sRPE*	4.586	0.0115	-44.193	14.493	-73.64	-20.07

Scatterplots indicated a potential non-linear relationship between percent change in OHRT and body-specific cumulative sRPE and arm-specific sRPE. There was no apparent deviation from dominant to non-dominant limb (**Figure 11**). After accounting for subject as a random effect, there was a significant linear relationship between arm-specific cumulative sRPE and percent change in OHRT (F=6.636, p=0.014). Although not noticeable in the scatterplots, there was a significant quadratic relationship between percent change in OHRT and arm-specific ACWR (F=4.99, p=0.011). There was also a significant quadratic relationship between body-specific cumulative sRPE (F=3.82, p=0.038). **Table 4** presents the model parameters from the models created between percent change in OHRT and training load.

Figure 11. Training load and percent change in OHRT across limbs. Linear line of best fit is represented by the dotted black line. (A) Arm-specific ACWR, (B) Body-specific ACWR, (C) Arm-specific cumulative sRPE, (D) Body-specific cumulative sRPE.
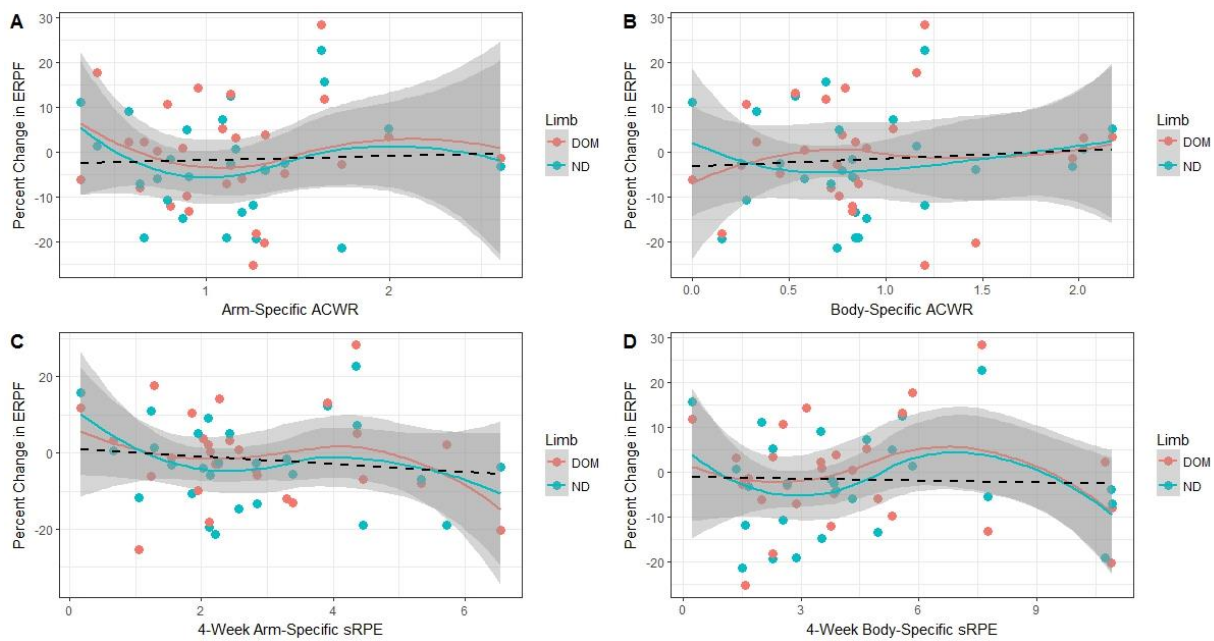
Table 4. Model parameters from statistical analyses between percent change in OHRT and training load. Upper bound and lower bound correspond to the 95% CI for the parameter estimate.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
OHRT	Linear	ID	Intercept			-14.472	5.612	-26.37	-2.78
			Limb	0.0991	0.7548	0.798	2.536	-4.18	5.77
			Arm-specific ACWR	1.7376	0.1933	4.095	3.107	-3.08	10.71
			Arm-specific Cumulative sRPE*	6.6367	0.0135	2.808	1.090	0.65	4.96
OHRT	Quadratic	ID*	Intercept			-3.008	2.555	-8.25	1.95
			Limb	0.1388	0.7126	0.798	2.142	-3.35	4.95
			Arm-specific ACWR*	8.2824	0.0008	-34.748	10.834	-57.85	-11.51
			Arm-specific Cumulative sRPE*	4.9934	0.0109	-21.842	11.178	-45.3	2.77
OHRT	Linear	ID	Intercept			-2.882	3.979	-10.48	4.73
			Limb	0.0798	0.7792	0.798	2.825	-4.79	6.39
			Body-specific ACWR	1.4329	0.2369	-3.403	2.842	-9.3	2.25
			Body-specific Cumulative sRPE	1.8962	0.1768	0.747	0.542	-0.29	1.79
OHRT	Quadratic	ID*	Intercept			-2.695	2.020	-6.47	1.03
			Limb	0.0833	0.7747	0.798	2.766	-4.49	6.09
			Body-specific ACWR	0.2896	0.7505	-2.114	12.330	-25.14	21.39
			Body-specific Cumulative sRPE*	3.8278	0.0382	-29.294	11.482	-50.44	-7.99

Behind the Back Reach Test

Scatterplots indicated a potential non-linear relationship between percent change in BBRT and arm-specific cumulative sRPE, so non-linear models were probed for this relationship (**Figure 12-C**). There was no linear relationship between percent change in BBRT and arm-specific ACWR (F= 2.82, p= 0.101) or arm-specific cumulative sRPE (F=0.088, p=0.768). There was no statistically significant linear relationship between percent change in BBRT and body-specific ACWR (F=1.77, p=0.195) or cumulative sRPE (F=01.20, p=0.295). There was also no significant quadratic effect of arm-specific ACWR (F=0.90, p=0.412) or cumulative sRPE (F=2.66, p=0.083) or body-specific ACWR (F=0.53, p=0.594) and cumulative sRPE (F=0.53, p=0.594). **Table 5** presents the model parameters for the models for percent change in BBRT.

Figure 12. Training load and percent change in BBRT across limbs. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE.
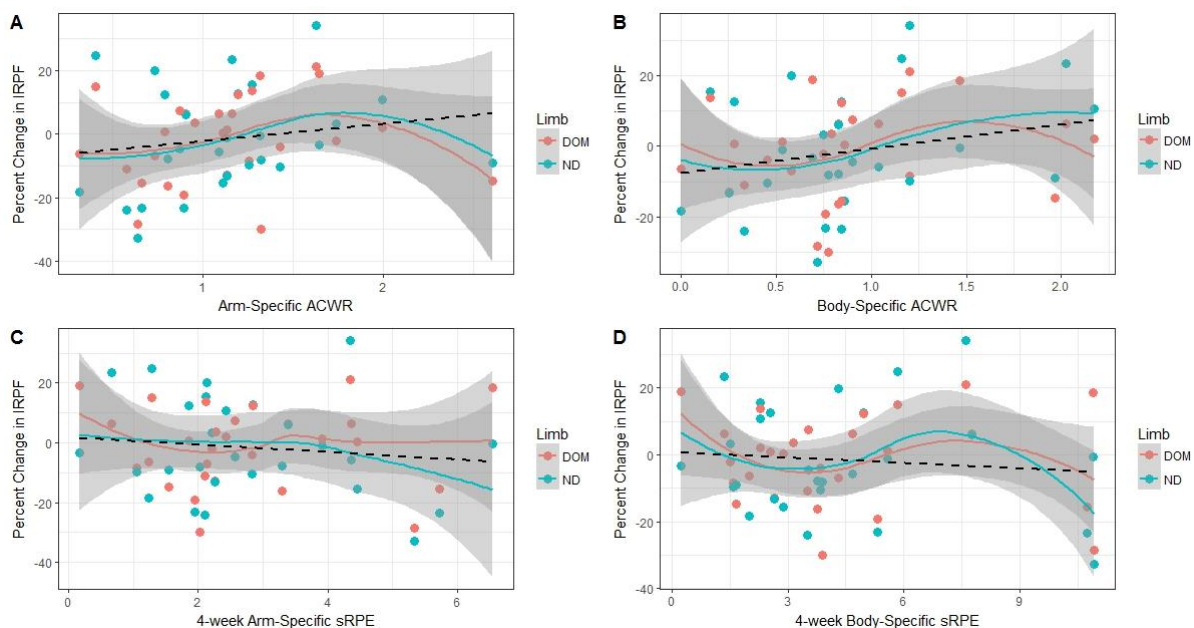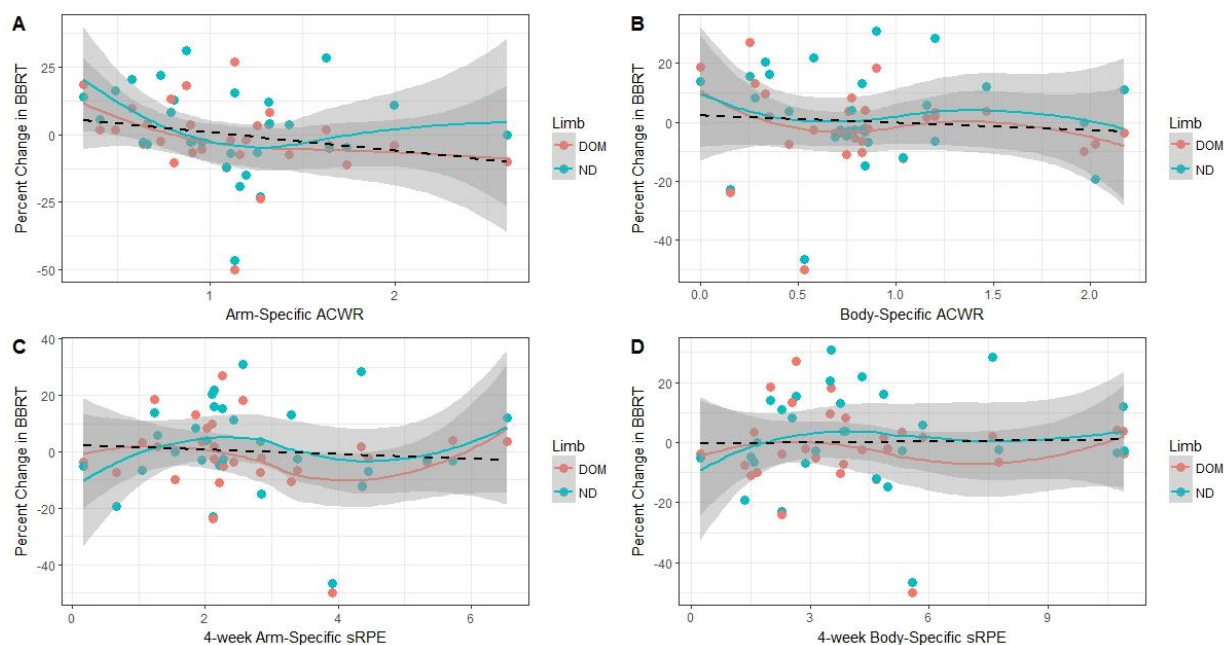
Table 5. Model parameters from the statistical analyses between percent change in BBRT and training load. Upper and lower boundaries correspond to the 95% confidence interval for the parameter estimate

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
BBRT	Linear	ID	Intercept			3.819	8.072	-12.95	19.99
		Time	Limb	1.8240	0.1860	3.419	2.532	-1.57	8.41
			Arm-specific ACWR	2.8160	0.1016	-6.392	3.809	-13.76	0.87
			Arm-specific Cumulative sRPE	0.0887	0.7687	0.426	1.431	-2.66	3.5
BBRT	Quadratic	ID*	Intercept			-2.943	4.724	-12.58	6.09
		Time	Limb	2.2162	0.1477	3.420	2.297	-0.98	7.82
			Arm-specific ACWR	0.9059	0.4117	7.461	13.546	-19.18	33.65
			Arm-specific Cumulative sRPE	2.6637	0.08302	-26.360	13.059	-52.56	2.48
BBRT	Linear	ID	Intercept			-0.851	4.892	-10.48	8.03
		Time	Limb	0.0869	0.7706	0.798	2.708	-4.79	6.39
			Body-specific ACWR	1.7717	0.1950	-4.012	3.014	-9.31	2.25
			Body-specific Cumulative sRPE	1.2039	0.2958	0.680	0.620	-0.36	1.78
BBRT	Quadratic	ID	Intercept			-1.302	2.928	-6.47	1.01
		Time	Limb	0.0939	0.7620	0.798	2.605	-4.49	6.09
			Body-specific ACWR	0.5311	0.5942	-5.289	12.666	-24.29	21.39
			Body-specific Cumulative sRPE	3.4457	0.0555	-29.486	11.723	-50.31	-7.98
								-12.95	19.99

There was no apparent non-linear trend, so only linear mixed models were probed to assess the relationship between training load variables and percent change in SLBT (**Figure 13**). After accounting for subjects and team as random effects, there was not a statistically significant relationship between percent change in SLBT and arm-specific ACWR (F=3.56, p=0.065) or arm-specific cumulative sRPE (F=0.071, p=0.792). There was no statistically significant relationship between percent change in SLBT and body-specific ACWR (F=0.308, p=0.581) or arm-specific cumulative sRPE (F=2.183, p=0.146). **Table 6** presents the model parameters from the statistical analyses between percent change in SLBT and training load.

Figure 13. Training load and percent change in SLBT across limbs. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE.
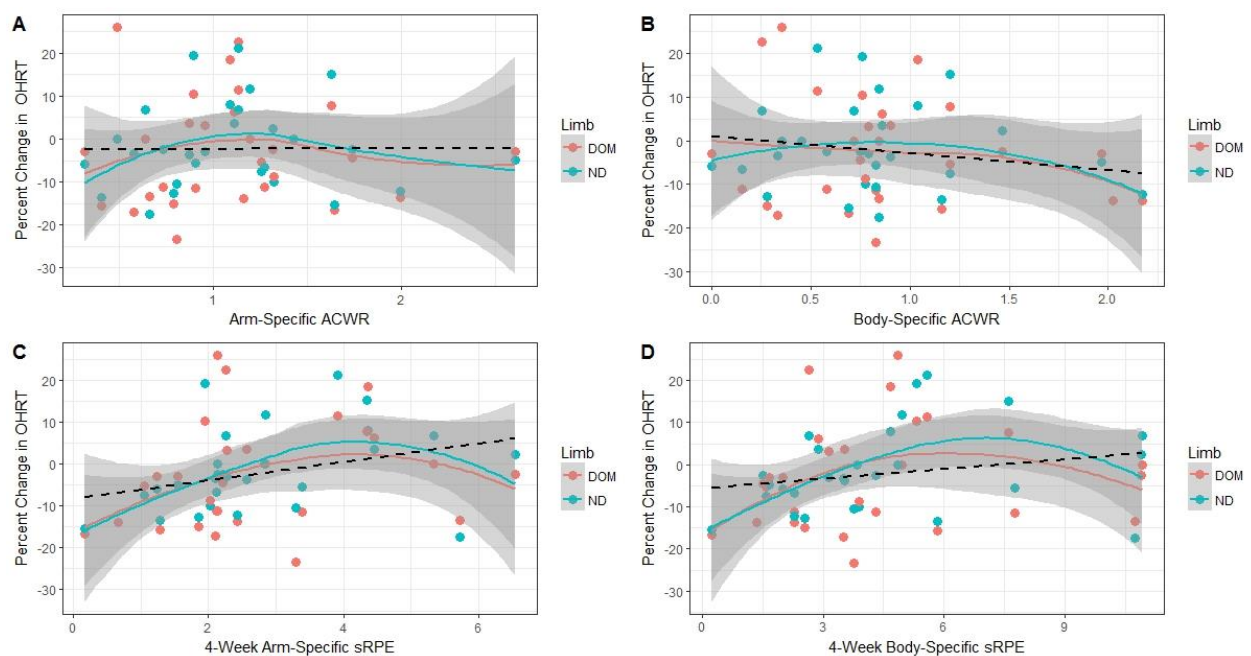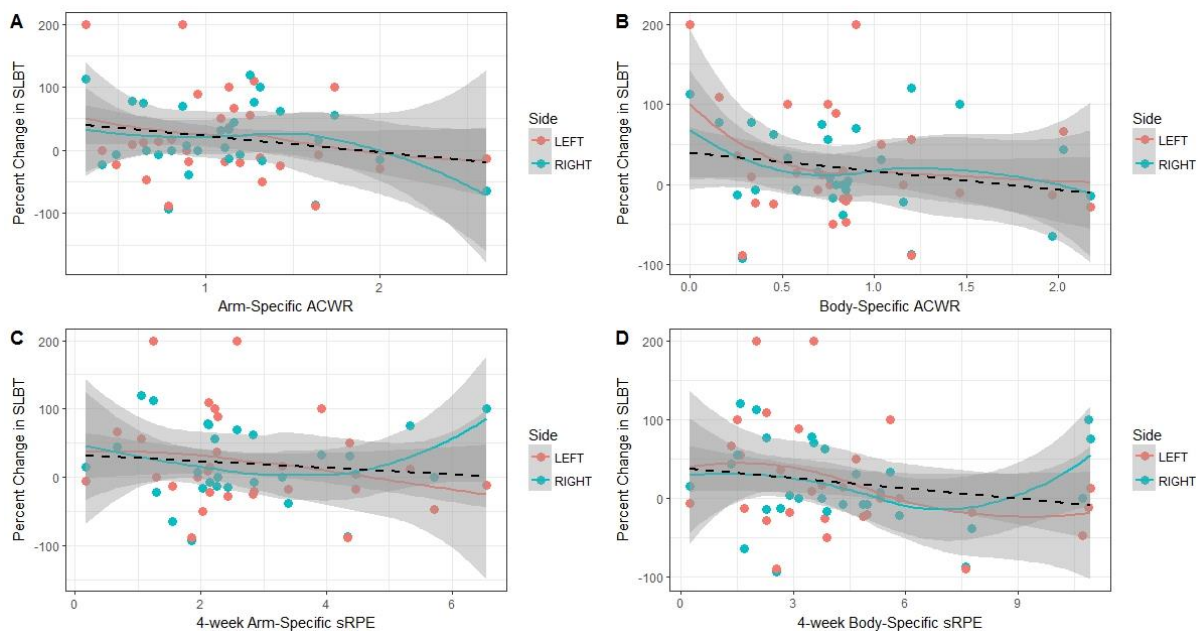
Table 6. Model parameters from the statistical analyses between percent change in SLBT and training load. Upper and lower boundaries correspond to the 95% confidence interval for the parameter estimate.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
SLBT	Linear	ID	Intercept			54.712	41.625	-35.14	141.35
		Team*	Limb	0.0790	0.7807	-3.700	13.166	-29.71	22.31
			Arm-specific ACWR	3.5642	0.6544	-29.519	15.636	-61.21	6.43
			Arm-specific Cumulative sRPE	0.0707	0.7920	1.468	5.522	-10.09	13.87
SLBT	Linear	ID	Intercept			15.172	39.590	-75.59	100.22
		Team*	Limb	0.0896	0.7668	-3.700	12.365	-29.88	20.48
			Body-specific ACWR	0.3087	0.5808	-8.036	14.464	-38.34	21.36
			Body-specific Cumulative sRPE	2.1832	0.1459	4.374	2.960	-3.15	10.34

There were no significant effects of arm-specific or body-specific training load on percent change in TROM, BBRT or SLBT. There were significant cubic relationships between body-specific cumulative load and IRPF and ERPF. There was also a significant relationship between body-specific and arm-specific training load and OHRT, with arm-specific ACWR and body-specific sRPE indicating a significant effect on percent change in OHRT. Although TROM is often cited as an upper extremity injury risk factor, the current study indicates that baseball specific training load did not influence the changes in TROM over the course of 4 weeks. Arm-specific sRPE measures based off throw count were not related to shoulder specific range of motion, contrary to our hypothesis. Changes in physical variables may be due to potentially singular large throwing bouts, as these are most prevalent following high volume throwing bouts.[28–30] Shoulder strength is significantly affected by baseball specific load, but this cubic relationship does not follow this study's hypothesis. The cubic nature of this relationship is similar to previous evidence in training load studies, which indicate that cumulative load and ACWR may have a non-linear relationship with injury risk.[63,65]

Although it is primarily considered a clinical measurement, there was a significant relationship between percent change in OHRT and both arm-specific and body-specific training load. This dynamic overhead movement may be able to assess motion at the scapulothoracic joint, glenohumeral joint, and elbow joint, but further research is required to assess how changes in this measure are related to each joint. It is hypothesized that losing ROM at any of these joints may be related to injury. Assessments of TROM only assess the rotational capabilities of the glenohumeral joint

while neglecting the humeroulnar joint or the scapulothoracic joint. The OHRT may be a good replacement to assess these joints in a clinical setting.

It is important to note that both body-specific and arm-specific variables were related to percent change in the injury risk factors, as well as ACWR and cumulative loads. Coaches, parents, players, and clinicians should understand the influence of total body training effects on specific injury risk factors to create evidence-based throwing programs. High cumulative total body loads may lead to a decrease in shoulder strength, and higher arm-specific ACWR may lead to negative changes in shoulder reach range of motion. Participation guidelines to limit high body-specific cumulative loads and high arm-specific ACWR may lead to lower negative effects from participation. Those in control of scheduling may be able to limit the amount of participations in a calendar month and require rest following throwing bouts to prevent negative effects.

Finally, there was no significant effect of limb and no interaction with limb for any independent variable. The dominant and non-dominant limb seemed to demonstrate similar changes over the testing period. Positive and negative changes may occur in tandem and may be due to factors that are not specific to a single limb, such as throws. Negative changes due to fatigue or positive changes due to strengthening may be more systemic in nature rather than local. This supports the use of assessing body-specific load for participation monitoring, as the arm-specific measures only gather dominant limb load.

Specific Aim 2: Musculoskeletal Fatigue Outcomes

<u>*Grip Strength*</u>

Scatterplots did not indicate a noticeable non-linear trend, so only linear relationships were probed (**Figure 14)**. There was no significant relationship between percent change in grip strength and arm-specific ACWR (F=2.85, p=0.098) or arm-specific cumulative sRPE (F=0.056, p=0.812). There was no significant relationship between percent change in grip strength and body-specific ACWR (F=1.00, p=0.322) or body-specific cumulative sRPE (F=1.21, p=0.277) variables. The relationship between arm-specific ACWR and percent change in grip strength approached statistical significance (F=2.85, p=0.098). **Table 7** presents the model parameters from the statistical analyses between percent change in grip strength and training load.

Figure 14. Training load and percent change in grip force across limbs. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE.
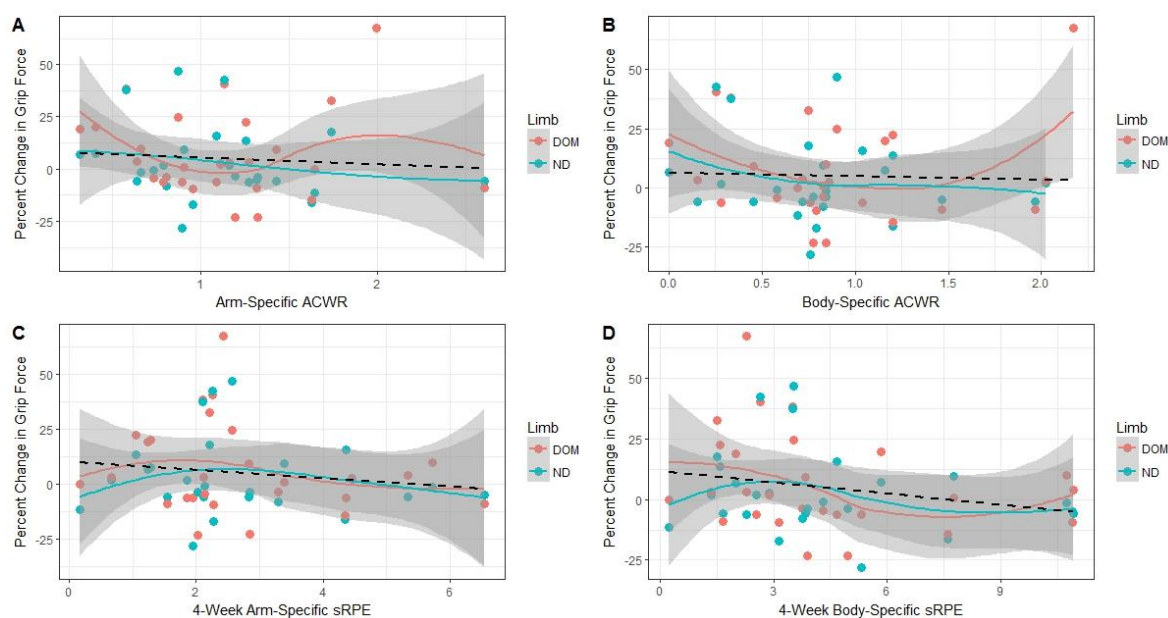
Countermovement Jump Height

There was no apparent non-linear relationship in the scatterplots, so linear mixed models were utilized to assess the relationship between percent change in jump height and power and training load (**Figure 15**). After accounting for subject as a random effect, there was no significant relationship between percent change in jump height and arm-specific ACWR (F=0.843, p=0.375) or arm-specific cumulative sRPE (F=0.982, p=0.339). There was also no significant relationship between percent change in jump height and body-specific ACWR (F=0.004, p=0.984) or body-specific cumulative sRPE (F=0.873, p=0.366). **Table 8** presents the model parameters from the statistical analyses between percent change in jump height and training load.

Figure 15. Training load and percent change in jump height. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE
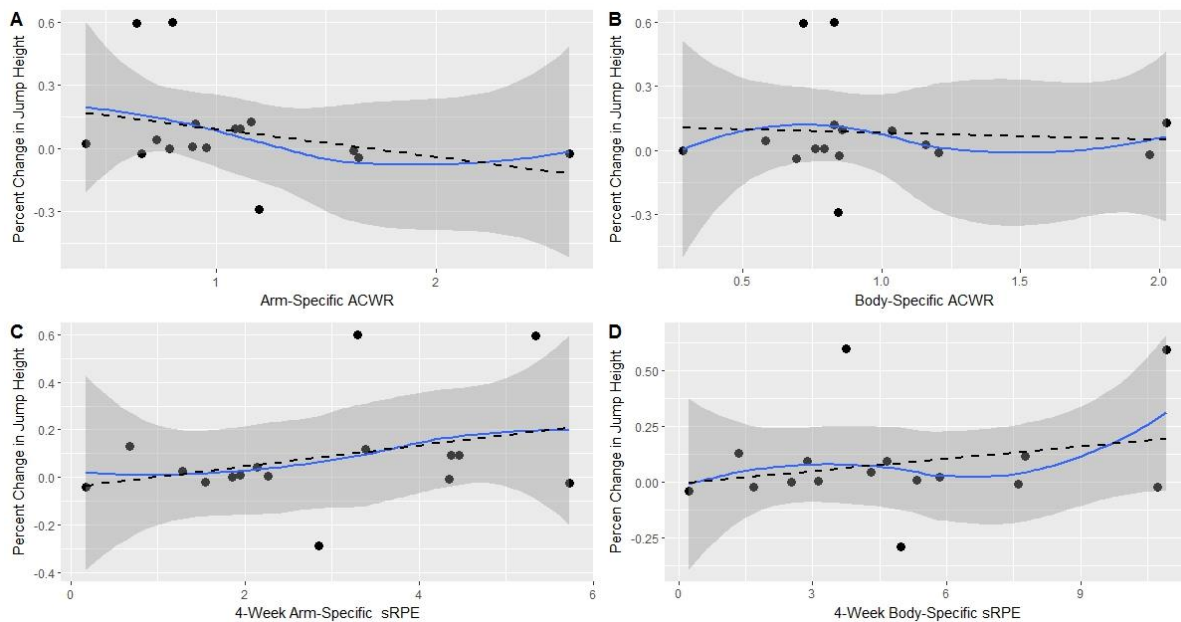
Countermovement Jump Power

There was no apparent non-linear relationship in the scatterplots, so linear mixed models were utilized to assess the relationship between percent change in jump height and power and training load (**Figure 16**). Similar to jump height, there was no significant relationship between percent change in jump power and arm-specific ACWR (F=1.045, p=0.325) or arm-specific cumulative sRPE (F=0.873, p=0.367). There was also no significant relationship between percent change in jump power and body-specific ACWR (F=0.004, p=0.984) or body-specific cumulative sRPE (F=0.873, p=0.366). **Table 8** presents the model parameters from the statistical analyses between percent change in jump power and training load.

Figure 16. Training load and percent change in jump power. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE
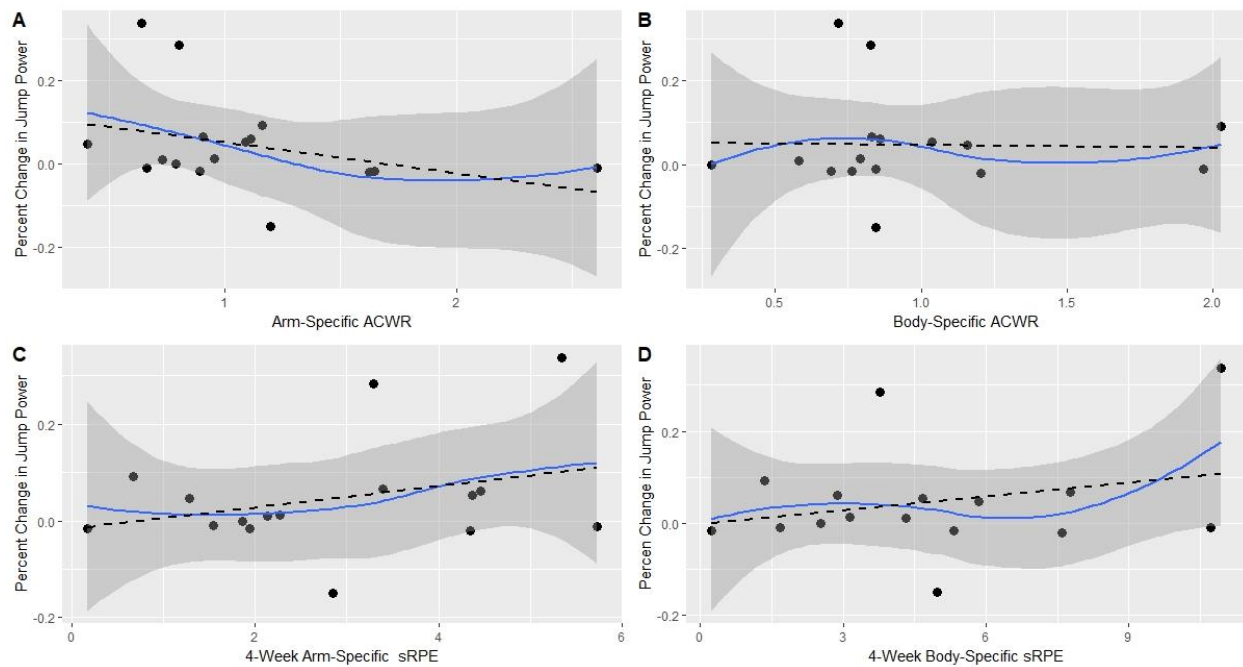
Table 7. Model parameters from the statistical analyses between percent change in grip strength and training load. Upper and lower boundaries correspond to the 95% confidence interval for the parameter estimate.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
Grip	Linear	ID*	Intercept			16.475	14.792	-15.490	48.470
		Team*	Limb	0.3455	0.5612	-1.878	3.196	-8.180	4.280
			Arm-specific ACWR	2.8551	0.0981	-7.439	4.403	-16.240	1.300
			Arm-specific Cumulative sRPE	0.0569	0.8126	0.387	1.624	-2.880	3.450
Grip	Quadratic	ID*	Intercept			10.066	14.249	-24.370	44.340
		Team*	Limb	0.3486	0.5596	-1.616	2.737	-6.790	3.520
			Arm-specific ACWR*	7.2045	0.0022	47.440	14.501	19.320	75.150
			Arm-specific Cumulative sRPE	0.6511	0.5271	3.041	14.325	-24.550	31.040
Grip	Linear	ID*	Intercept			9.151	13.823	-22.550	40.600
		Team*	Limb	0.3337	0.5682	-1.863	3.225	-8.190	4.340
			Body-specific ACWR	1.0054	0.3220	-4.063	4.052	-12.610	4.320
			Body-specific Cumulative sRPE	1.2172	0.2775	0.860	0.780	-0.750	2.310
Grip	Quadratic	ID*	Intercept			9.349	12.470	-20.580	39.100
		Team	Limb	0.3094	0.5827	-1.820	3.325	-8.250	4.430
			Body-specific ACWR	0.5353	0.5896	13.766	13.457	-33.060	60.460
			Body-specific Cumulative sRPE	0.7438	0.4816	-3.694	17.388	-36.000	30.040

Table 8. Model parameters from the statistical analyses between percent change in the countermovement jump variables and training load. Upper and lower boundaries correspond to the 95% confidence interval for the parameter estimate.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
Jump Height	Linear	ID	Intercept			0.092	0.185	-0.250	0.440
			Arm-specific ACWR	0.8436	0.3751	-0.102	0.111	-0.310	0.110
			Arm-specific Cumulative sRPE	0.9821	0.3398	0.035	0.035	-0.030	0.100
Jump Height	Linear	ID	Intercept			-0.004	0.187	-0.350	0.340
			Body-specific ACWR	0.0040	0.9847	-0.002	0.134	-0.250	0.240
			Body-specific Cumulative sRPE	0.8738	0.3669	0.018	0.019	-0.010	0.050
Jump Power	Linear	ID	Intercept			6.256	9.738	-12.034	24.526
			Arm-specific ACWR	1.0452	0.3253	-6.000	5.868	-17.020	5.022
			Arm-specific Cumulative sRPE	0.8203	0.3816	1.695	1.872	-1.820	5.211
Jump Power	Linear	ID	Intercept			-1.367	9.844	-19.857	17.120
			Body-specific ACWR	0.0207	0.8877	1.017	7.062	-12.247	14.282
			Body-specific Cumulative sRPE	1.0010	0.3353	1.033	1.033	-0.906	2.972

Countermovement jump variables and grip strength were not related to arm-specific or body-specific training load variables. Jump height and grip strength are often used to as clinical assessments of fatigue in athletes, and there is evidence to suggest that they may be related to fatigue in field sports. In baseball players, there does not seem to be a relationship between arm-specific or body-specific training load and jump height, jump power, or grip strength. While jump height has previously been linked to neuromuscular fatigue and grip strength is theorized to contribute to injury, there is minimal information regarding the link between these measures and injury. Future work should address the influence of jump height and grip strength on baseball related injury.

Specific Aim 3: Subjective Well-Being

For the well-being variables, time was included in the model, due to the lack of time being incorporated into the dependent variables. The inclusion of time as a dependent variable assisted with accounting for any potential effects of school, as the time is set as the as the week number since the start of the semester. Subject and team were probed as potential random effects, and the arm-specific and body-specific training load variables were assessed in separate models. Data was visualized on scatterplots to assess if the relationship between the well-being variables and training load was linear or non-linear.

Average Weekly Readiness

There was no apparent polynomial trend to the scatterplots, so linear models were utilized to assess the relationship between weekly average readiness and training load measures (**Figure 17**). After accounting for subject and team, a significant linear relationship was present between weekly readiness and arm-specific ACWR (F=4.06, p=0.047). For body-specific training load variables, there was a significant linear relationship between weekly readiness and body-specific ACWR (F=5.91, p=0.017). **Table 9** presents the model parameters between average weekly readiness and training load.

Figure 17. Training load and average weekly readiness. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE
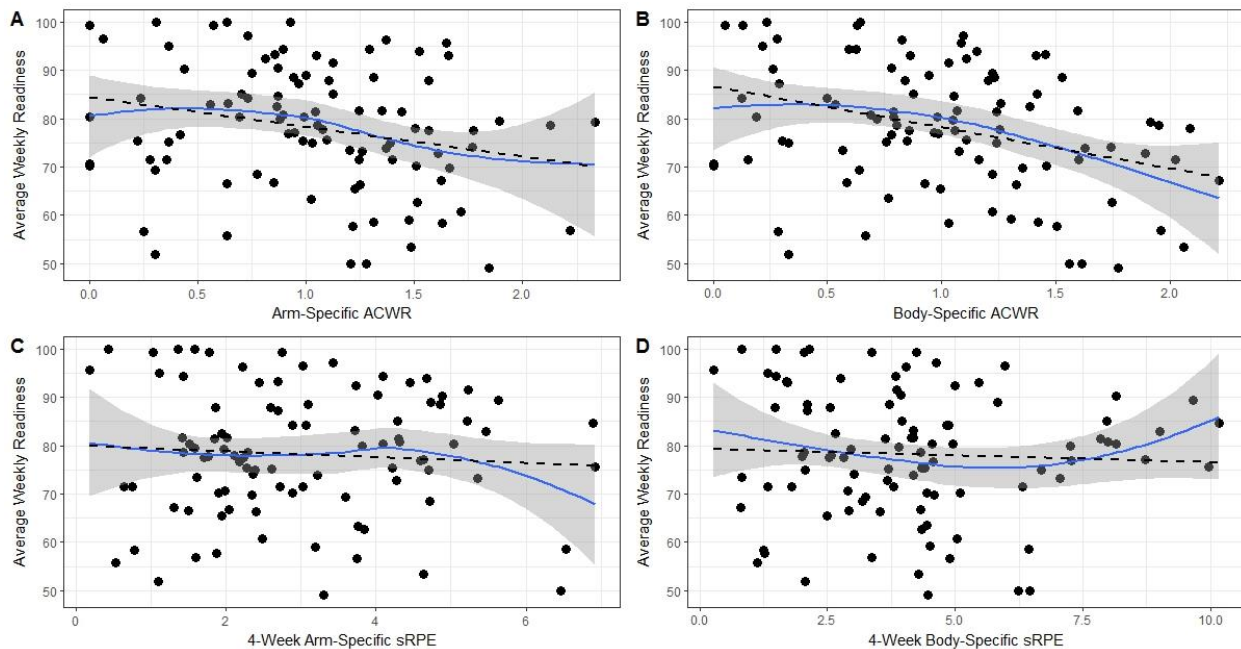
Average Weekly Fatigue

When visualized on a scatterplot, there was no apparent polynomial relationship (**Figure 18**). Therefore, linear models were utilized to assess the relationship between weekly average fatigue and training load measures. After accounting for subjects and team, there was no significant relationship between weekly fatigue and arm-specific training ACWR ($F=0.018$, $p=0.892$) or arm-specific cumulative sRPE ($F=2.82$, $p=0.0961$). Additionally, there was no influence of any body-specific training load variables on weekly any of the training load variables and weekly average fatigue and body-specific ACWR ($F=0.167$, $p=0.684$) or body-specific cumulative sRPE ($F=1.40$, $p=0.239$). **Table 10** presents model parameters between average weekly fatigue and training load.

Figure 18. Training load and average weekly fatigue. Linear line of best fit is represented as the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE

Average Weekly Stress

There was no apparent polynomial relationship, so linear models were used to assess the relationship between weekly average stress and training load (**Figure 19**). When accounting for subjects' random effects, there was a significant linear association between weekly average stress and arm-specific ACWR (F=5.03, p=0.027) and arm-specific cumulative sRPE (F=16.07, p<0.001). After accounting for subject as a random effect, there was a significant relationship between weekly average stress and body-specific ACWR (F=6.92, p=0.010). There was a significant effect of time in both the arm-specific (F=12.06, p<0.001) and body-specific model (F=6.92, p=0.010). **Table 11** presents the model parameters between average weekly stress and training load.

Figure 19. Training load and average weekly stress. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE
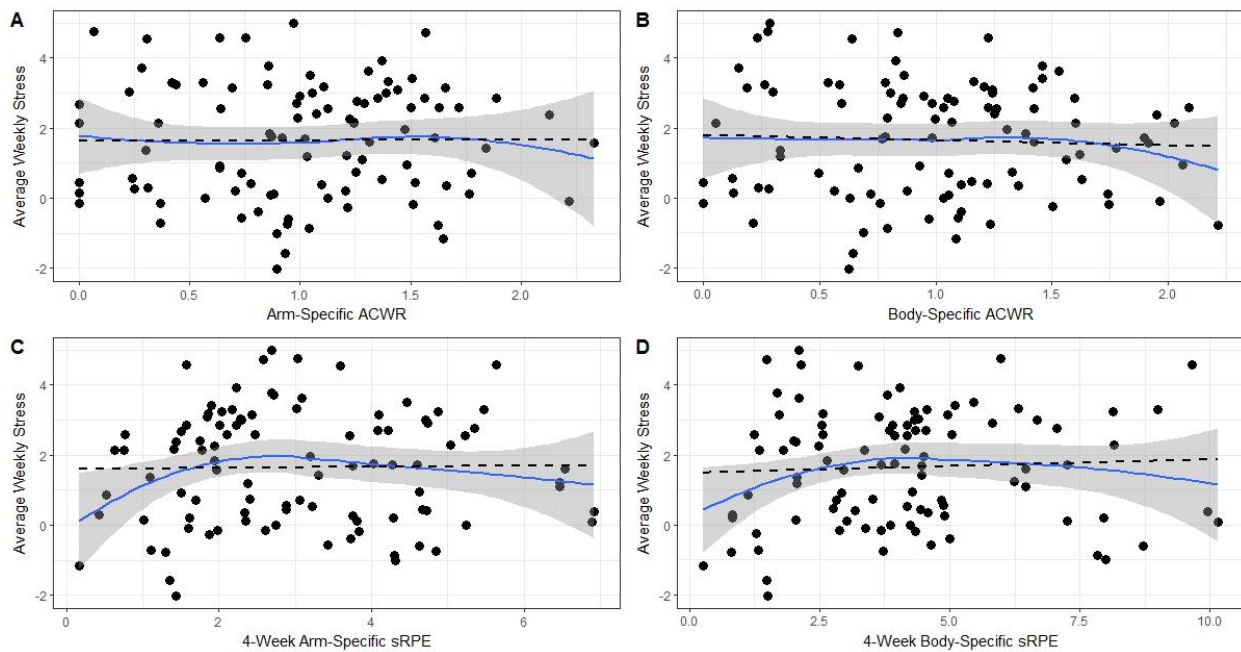
Since there was a curvilinear nature to both arm and body-specific ACWR, quadratic models were probed (**Figure 20**). After accounting for subjects and team as random effects, there was a significant linear relationship between arm-specific ACWR and average weekly soreness intensity (F=6.68, p=0.011). There was also a significant linear relationship between body-specific ACWR and soreness intensity (F=22.57, p<0.001) as well as a significant quadratic relationship between weekly average soreness and body-specific ACWR (F=19.27, p<0.001). There was no statistically significant effect of time on weekly average soreness intensity. **Table 12** presents model parameters and statistics for the analyses between average weekly soreness intensity and training load.
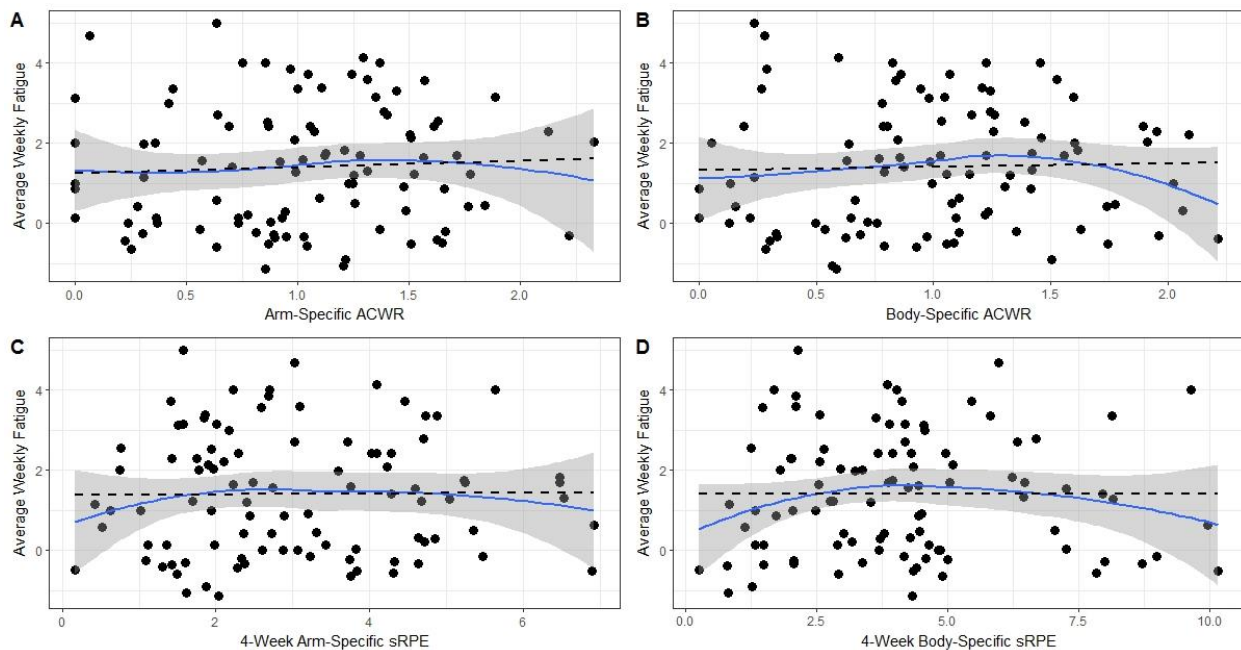
Figure 20. Training load and average weekly soreness intensity. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE.

Table 9. Model parameters from the statistical analyses between average weekly readiness and training load. Upper and lower boundaries correspond to the 95% confidence interval for the parameter estimate.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
Readiness	Linear	ID*	Intercept			90.825	8.061	74.05	107.80
		Team*	Week	2.7845	0.0989	-0.676	0.406	-1.48	0.11
			Arm-specific ACWR	1.4087	0.2387	-2.270	1.913	-6.01	1.46
			Arm-specific Cumulative sRPE	4.0631	0.0471	-1.854	0.920	-3.65	0.01
Readiness	Linear	ID*	Intercept			94.211	8.956	75.66	113.10
		Team*	Week	3.8362	0.0534	-0.845	0.432	-1.68	0.01
			Body-specific ACWR	2.5441	0.1145	-3.030	1.900	-6.85	0.68
			Body-specific Cumulative sRPE	5.9133	0.0171	-1.630	0.670	-2.89	-0.24

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Table 10. Model parameters from the statistical analyses between average weekly fatigue and training load. Upper and lower boundaries correspond to the 95% confidence interval for the parameter estimate.

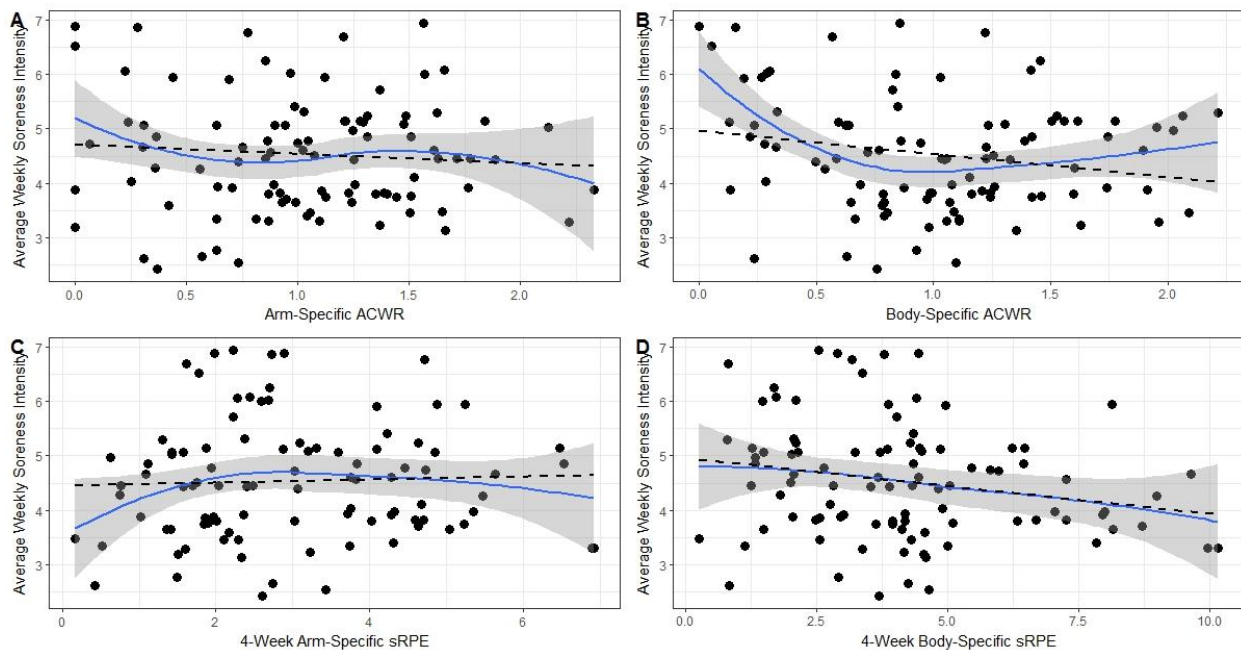| DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
Fatigue	Linear	ID*	Intercept			2.663	0.725	1.27	4.10
		Team	Week	3.4954	0.0652	-0.080	0.043	-0.16	0.00
			Arm-specific ACWR	0.0184	0.8926	-0.027	0.200	-0.41	0.36
			Arm-specific Cumulative sRPE	2.8260	0.0961	-0.174	0.104	-0.37	0.04
Fatigue	Linear	ID*	Intercept			2.583	0.781	1.12	4.10
		Team	Week	3.2116	0.0769	-0.083	0.046	-0.17	0.00
			Arm-specific ACWR	0.1667	0.6842	-0.082	0.202	-0.47	0.31
			Arm-specific Cumulative sRPE	1.4011	0.2396	-0.090	0.076	-0.23	0.07

Table 11. Model parameters from the statistical analyses between average weekly stress and training load. Upper and lower boundaries correspond to the 95% confidence interval for the parameter estimate.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
Stress	Linear	ID*	Intercept			4.690	0.635	3.44	5.95
			Week	12.0643	0.0008	-0.144	0.042	-0.22	-0.06
			Arm-Specific ACWR	5.0326	0.0277	-0.440	0.196	-0.81	0.05
			Arm-Specific Cumulative sRPE	16.0725	0.0001	-0.416	0.104	-0.62	-0.2
Stress	Linear	ID*	Intercept			3.760	0.688	2.42	5.09
			Week	6.9298	0.0101	-0.126	0.048	-0.21	-0.03
			Body-Specific ACWR	7.5185	0.0076	-0.571	0.208	-0.97.	-0.16
			Body-Specific Cumulative sRPE	1.3968	0.2403	-0.092	0.078	-0.24	0.06

Table 12. Model parameters from the statistical analyses between average soreness intensity and training load. Upper and lower boundaries correspond to the 95% confidence interval for the parameter estimate

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
Soreness	Linear	ID*	Intercept			5.113	0.532	4.10	6.11
		Team	Week	0.7398	0.3922	0.031	0.036	-0.03	0.10
			Arm-specific ACWR	6.6656	0.0116	-0.443	0.172	-0.77	-0.11
			Arm-specific Cumulative sRPE	1.3966	0.2406	-0.098	0.083	-0.28	0.06
Soreness	Linear	ID*	Intercept			4.925	0.568	3.85	5.96
		Team	Week	2.6334	0.1084	0.059	0.036	-0.01	0.12
			Body-specific ACWR	22.5763	0.0000	-0.754	0.159	-1.06	-0.44
			Body-specific Cumulative sRPE	0.0419	0.8382	-0.012	0.058	-0.13	0.09
Soreness	Quadratic	ID*	Intercept			4.122	0.418	3.31	4.91
		Team	Week	2.8709	0.0940	0.058	0.034	-0.01	0.12
			Body-specific ACWR	19.2785	<0.0001	2.810	0.765	1.38	4.34
			Body-specific Cumulative sRPE	0.0208	0.9794	0.024	0.839	-1.59	1.63

Specific Aim 3 Summary:

Arm-specific and body-specific training load were significant fixed effects of readiness, stress, and soreness intensity. There was no significant effect of training load on self-reported fatigue. Self-reported questionnaires could be used to indicate daily athlete subjective well-being and preparedness, and these responses are linked to their current training load. Clinicians should be able to identify when negative self-reported well-being responses are present, as they may influence other aspects of an athlete, such as their performance, injury risk, or personal life outside of sport. Managing athlete load with appropriate scheduling may reduce negative changes to readiness, stress and soreness intensity. Current practices often stress reducing cumulative load to prevent from entering an overreached training state,[177] but arm-specific and body-specific ACWR is related to readiness, stress, and soreness intensity. The use of subjective well-being surveys may also be used to corroborate the findings from training load surveys. When high training load values are present, the subjective well-being surveys can be used to indicate if the negative levels of soreness, stress, or readiness are present, so clinicians may intervene before entering a non-functional overreaching training state.[255] Finally, time is a major influencer of stress, when measures as the week from the start of the semester. Although school related load was not assessed in this study, there may be a significant effect of school and studying on stress levels. Changes in stress on subjective surveys could assist with indicating when a baseball player is experiencing high amounts of stress external to sport.

Specific Aim 4: Baseball Performance

Fastball velocity

Scatterplots did not indicate a potential non-linear relationship between percent change in fastball velocity and training load variables, so only linear mixed models were assessed (**Figure 21**). After accounting for subjects as random effects, there was no significant relationship between percent change in fastball velocity and arm-specific ACWR (F=1.49, p=0.229) or arm-specific cumulative sRPE (F=0.156, p=0.695). There was no significant relationship between percent change in fastball velocity and body-specific ACWR (F=1.70, p=0.201) or body-specific sRPE (F=0.658, p=0.4229). **Table 13** presents the model parameters for the statistical analyses.

Figure 21. Training load and percent change in fastball velocity. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE
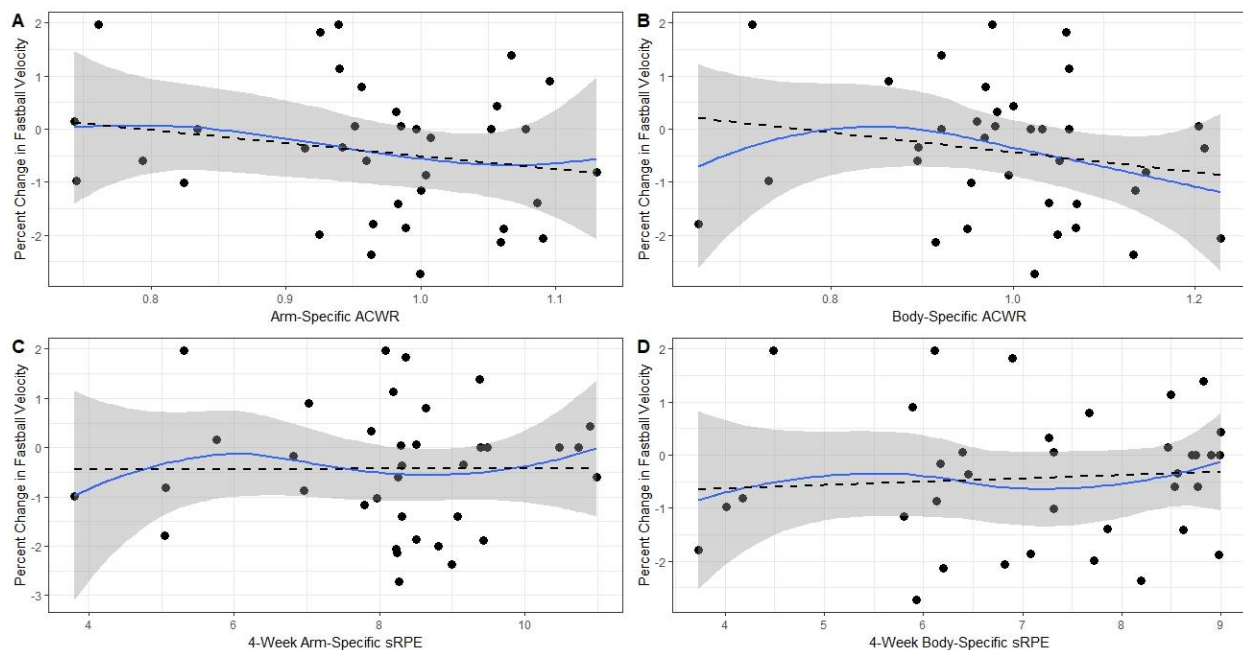
Fastball Spin Rate

Scatterplots did not indicate a potential non-linear relationship between percent change in fastball spin rate and training load variables, so only linear mixed models were assessed (**Figure 22**). After accounting for subjects as random effects, there was no significant relationship between percent change in fastball spin rate and arm-specific ACWR (F=0.005, p=0.942) or arm-specific cumulative sRPE (F=0.011, p=0.917). There was no significant relationship between percent change in fastball spin rate and body-specific ACWR (F=2.26 p=0.147) or body-specific sRPE (F=0.171, p=0.681). **Table 13** presents the model parameters and statistics of the analyses between percent change in fastball spin rate and training load.

Figure 22. Training load and percent change in fastball spin rate. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE

Exit Velocity

Scatterplots did not indicate a potential non-linear relationship between percent change in exit velocity and training load variables, so only linear mixed models were assessed (**Figure 23**). After accounting for subjects as random effects, there was no significant relationship between percent change in exit velocity and arm-specific ACWR (F=0.021, p=0.885) or arm-specific cumulative sRPE (F=0.002, p=0.989). There was no significant relationship between percent change in exit velocity and body-specific ACWR (F=0.005 p=0.939) or body-specific sRPE (F=0.011, p=0.918). **Table 13** presents the model parameters and statistics of the analyses between percent change in exit velocity and training load.
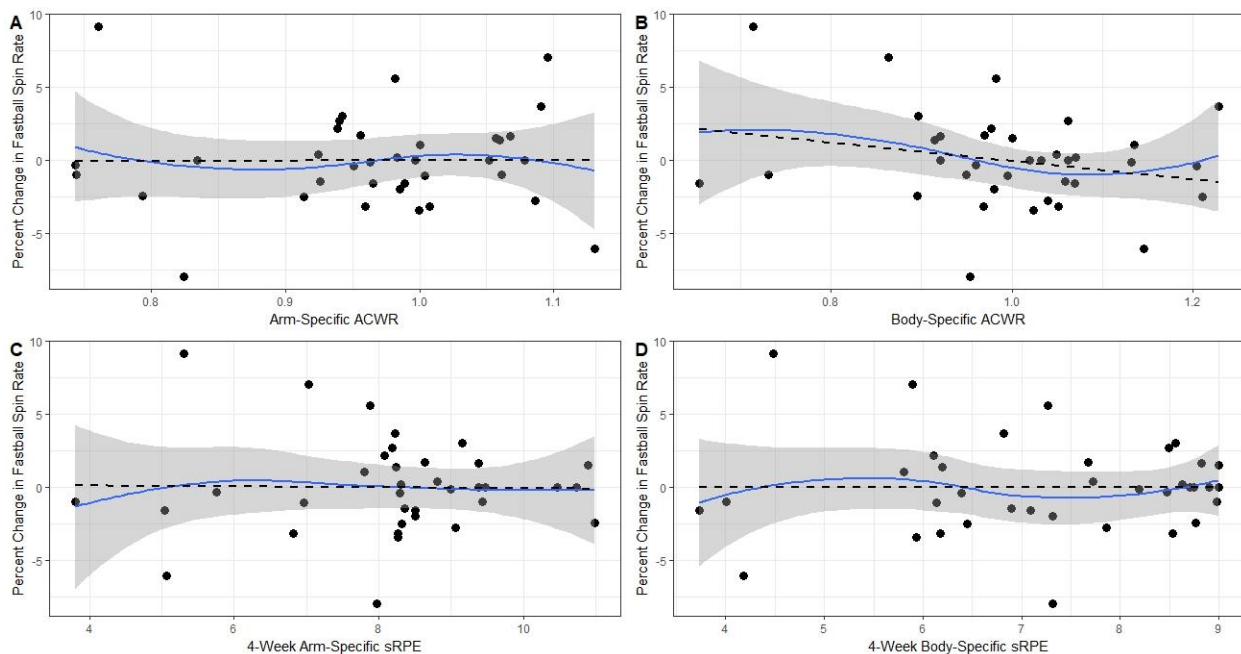
Figure 23. Training load and percent change in exit velocity. Linear line of best fit is represented by the dotted black line. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE
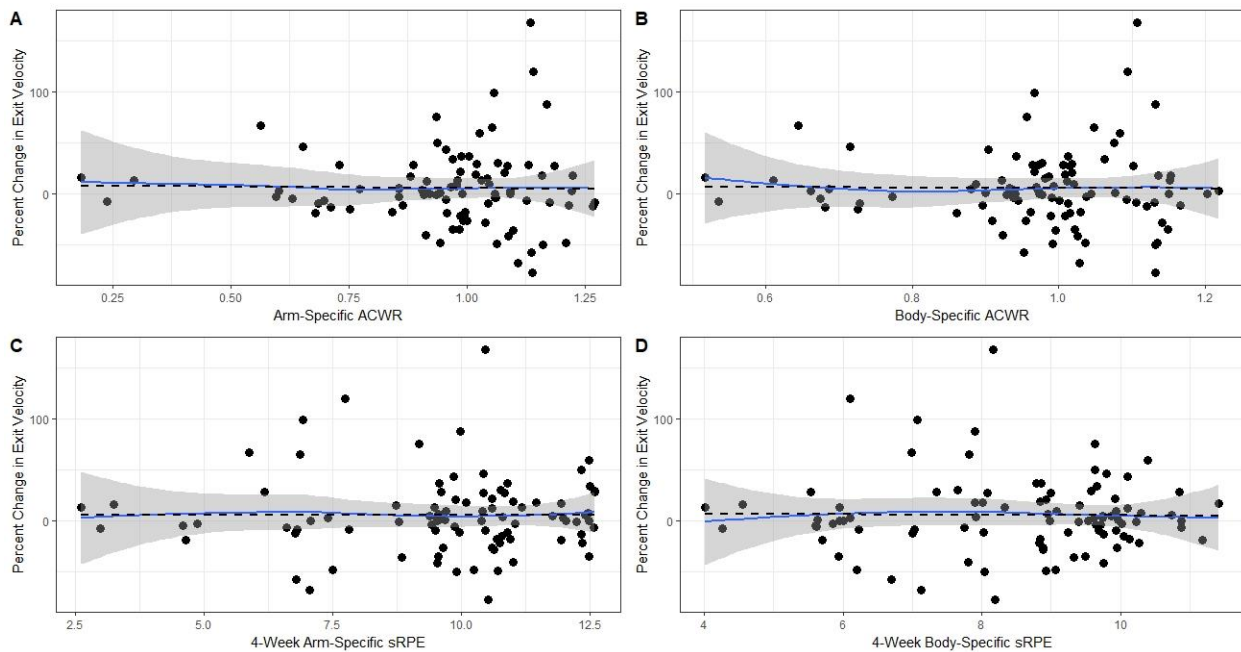
Table 13. Model parameters from the statistical analyses between percent change in baseball performance variables and training load. Upper and lower boundaries correspond to the 95% confidence interval for the parameter estimate

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	Lower Bound	Upper Bound
FB Velocity	Linear	ID	Intercept			1.755	2.115	-2.32	5.83
			Arm-specific ACWR	1.4981	0.2296	2.219	2.219	-6.99	1.56
			Arm-specific Cumulative sRPE	0.1565	0.695	0.053	0.136	-0.2	0.31
FB Velocity	Linear	ID	Intercept			0.988	1.756	-2.39	4.37
			Body-specific ACWR	1.7032	0.2009	-2.271	1.740	-5.62	1.08
			Body-specific Cumulative sRPE	0.6585	0.4229	0.116	0.143	-0.16	0.39
FB Spin Rate	Linear	ID	Intercept			-0.138	5.671	-11.07	10.79
			Arm-specific ACWR	0.0053	0.9425	0.432	5.951	-11.04	11.90
			Arm-specific Cumulative sRPE	0.0109	0.9176	-0.380	0.364	-0.74	0.66
FB Spin Rate	Linear	ID	Intercept			5.657	4.582	-3.17	14.49
			Body-specific ACWR	2.2669	0.147	-6.837	4.541	-15.59	1.91
			Body-specific Cumulative sRPE	0.1712	0.6817	0.155	0.375	-0.56	0.88
Exit Velocity	Linear	ID	Intercept			7.996	22.884	-36.58	52.57
			Arm-specific ACWR	0.0210	0.885	-2.9836	20.580	-43.07	37.10
			Arm-specific Cumulative sRPE	0.0002	0.982	0.02479	1.831	-3.54	3.59
Exit Velocity	Linear	ID	Intercept			9.4812	33.362	-55.00	51.00
			Body-specific ACWR	0.0058	0.0939	-2.1098	27.701	-56.07	51.85
			Body-specific Cumulative sRPE	0.0106	0.9182	-0.2412	2.341	-4.80	4.31

Specific Aim 4 Summary

Although some previous non-academic literature exists to suggest that sports related load and performance outcomes may be linked,[81] the results here suggest that there is limited relationship between training load and fastball velocity, fastball spin rate, and exit velocity. Instead of utilizing baseball performance outcomes to identify when baseball players may be at risk for injury, there may be other more suitable measures that can be assessed with an athletic trainer or strength and conditioning coach. Baseball training habits do not necessarily lead to a change in baseball performance as well. Instead, coaches and players may want to focus on the quality of their baseball participation rather than the quantity of it. Sport participation is multifaceted as well, and it may be difficult to fully detect the effectiveness of baseball participation through only the variables that were collected here.

Future Research

While this study indicates that there are relationships between baseball participation and physical factors related to injury, it does not address how the baseball participation at different positions specifically influences physical factors. Justification can be made that pitchers will likely have different training loads and respond differently to throwing than their position playing counterparts. Additionally, evidence suggests that pitchers suffer more injuries than their position playing counterparts.[5] Therefore, future research should identify how throwing load and overall body load influence changes in physical factors at those in different positions. This information may lead to better evidence-based throwing programs and rest guidelines.

The influence of body-specific and arm-specific training load on percent change in OHRT suggests that this measurement is related to baseball specific training load. Little is known about this test, so future research should continue to identify why this test may be related to baseball specific load. The OHRT incorporates motion from the elbow joint, glenohumeral joint, and scapulothoracic articulation, all of which have been suggested to contribute to throwing load in baseball players. Additionally, increases or decreases in this measurement may be due to changes in range of motion in any of the aforementioned joints, so dissemination of the OHRT may provide more granular information regarding range of motion losses at a specific joint.

Finally, future research should investigate utilizing total load measures of internal and external training load over simple throw counts, as throw counts are incorporated into total load measures. Throw counts can be slightly misleading, and under reported, so adding a measure of internal load may also assist with validity throwing load. Future research should explore the validity of self-reported throw loads, the use of automated throw assessments, and the use of coach reported throw counts. These assessments may indicate how load is applied, and how the load is reported. There are significant amounts of missing data that may be accounted for with better assessment methods.

Limitations

This study is not without limitations. Athletes were asked to report their daily readiness and training load each day before and after practice. Survey responsiveness was poor for both the subjective well-being and training load surveys. Higher responsiveness may have led to more generalizable results and limited the need for participants to re-enter in the data analysis. Participants were told to take the training

load survey within 30 minutes after activity, but there was no specific control for this measure. Recall bias could have influenced the results, and limited the accuracy of the self-reported throws, durations, or RPE of the training session. Future research may address how to best collect self-reported measures to ensure accuracy and validity of the data collected.

Participants were asked to report their overall throw count, but there was no control for what type of throw it was. In the context of this study, a throw from the field, off the mound, or in a bullpen were all weighted equally, even though there is evidence to suggest that these may not create the same forces on the arm.[19,138] Internal load measures were taken alongside throw counts to determine external loads, but there is no indication that RPE measures truly reflect physiological responses in this populations. The sport of baseball requires are far less aerobic exertion, so sRPE based load measures may be slightly skewed in a more anaerobic sport. Future research should identify if sRPE based measures accurately reflect physiological or psychological measures associated with overtraining or increased injury risk.

Although the use of sRPE methods of training load assessments is novel in a baseball specific population, there is limited evidence to suggest appropriate thresholds and cutoffs from this data. Relationships were detected within the models, but they only reflect the percent changes in variables theoretically linked to injury risk, and not specific injury risk itself. The current study is unable to draw conclusions regarding specific cutoff thresholds, because these data are continuous in nature, and not specific injury risk measures. Future studies should utilize sRPE methods to assess training loads baseball athletes to determine if ACWR and cumulative load measures are similar

to current research, or if different thresholds of ACWR are needed to reflect the specific sport demands.

Finally, the participants in this study are high-level collegiate baseball athletes, so conclusions may not translate to younger baseball players. The participants also only participate on one team at a time, which is much different than a young baseball athlete who may participate on multiple teams at one time. The participants in this study also had access to athletic trainers and strength and conditioning coaches. These health care professionals may be able to alter training loads in this study that may be unaccounted for in the data. The participants of this study are also college students, with a considerable about of stresses from outside of sport. Future research should address how baseball specific training loads influence these variables in a younger cohort, where access to health care professionals is limited, participations may be occurring across multiple teams, and stress external to sport is much lower than in this specific study.

Clinical Application

Coaches, athletic trainers, and strength coaches may be able to use the current measures in conjunction to provide a comprehensive assessment of how baseball participation influences the mental and physical health of baseball players. Arm-specific and body-specific training loads were related to subjective measures of well-being. When implemented together, these surveys may corroborate evidence of overreaching, as indicated by high training load and negative changes in stress, readiness, and soreness. If high training loads are present, and negative well-being scores are

reported, then the negative changes are likely a result of baseball participation. Coaches, parents, and clinicians can alter the training or playing schedule to allow for more recovery that allows the negative changes to dissipate. Negative changes without the presence of large changes to training load may be equally as important, as the alterations to the subjective well-being may be due to factors external to sport while still influencing the athlete's injury risk. Participating while negative changes are present can push an athlete into a non-functional overreaching state, where the negative changes are present for weeks or months. Since subjective well-being scores are related to injury,[202,216] this should be avoided to prevent injury, illness, or burnout.

Negative changes in training load or subjective well-being may also prompt clinicians to investigate an athlete's physical health. The use of the reach test and grip strength tests may be able to provide an indicator of the physical health of the baseball player with a clinically feasibly testing session. The reach tests and grip strength assessments are designed to assess gross changes in shoulder physical function with time sensitive and reliable assessment methods. Negative changes in the reach test or grip strength may prompt further physical examination, such as shoulder range of motion or strength assessments. While the current study did not find a relationship between training load and the baseball-specific injury risk factors, there were no injuries reported by the participants during the study duration. It may be that the participants did not have large enough changes to ROM and strength that predisposed them to injury, or that this population pool is well equipped to deal with the changes from throwing. With the link between shoulder ROM and injury,[37,38,40] assessing the shoulder ROM and

strength may provide clinicians with significant information regarding physical health or injury risk of the baseball player.

While the methods present in the current study may be useful for injury prevention, they can also be used to appropriately plan baseball participation when returning from injury or from the offseason. Throwing programs that prescribe high loads too quickly may lead to high ACWR and low scores of subjective well-being. Appropriate rest intervals between throwing bouts allows for recovery of negative changes that may result from activity. The subjective well-being surveys used in tandem with a throwing program can provide feedback to ensure that functional overreaching is occurring, and arm fitness is being created. Consistent negative subjective well-being scores could be indicative of non-functional overreaching,[237,255] and indicate that an athlete is at risk for injury or illness.[202] Clinicians and coaches should collaborate to create throwing, training, and playing programs that allow for proper rest and recovery times to mitigate negative changes from baseball participation.

Conclusions

This is the first study to utilize sRPE and ACWR measures in a baseball sport setting, and results indicate that body-specific and arm-specific training load measures are related to measures of shoulder strength, clinical reach tests, and subjective well-being variables. Arm-specific and body-specific variables should be recorded to track baseball specific training load to determine when baseball players are overreaching during baseball participation. Body-specific cumulative loads are related to shoulder strength outcomes, so baseball coaches and parents should appropriately prescribe

baseball training and playing to limit the negative effects on shoulder strength. Additionally, high body-specific ACWR values are linked to changes in muscle soreness and clinical reach tests, so appropriate training programs and rest cycles should be utilized to prevent negative changes from overall sport participation. While the current study is unable to identify thresholds for negative changes, it can serve as a springboard for other research. Future research should be dedicated to understanding how baseball specific training influences injury risk in baseball players. Additionally, future research should be dedicated to the understanding of fatigue in baseball players. The results here indicate that changes are consistent across limbs, so future research may be needed to identify if negative changes due to fatigue are local or more systemic in nature.

CHAPTER 5: MANUSCRIPT 1

INFLUENCE OF BASEBALL SPECIFIC TRAINING LOAD ON UPPER EXTREMITY INJURY RISK FACTORS

Overview

Background: Baseball players with high pitch counts demonstrate lower shoulder strength compared to those with a moderate and low amount of pitches, but pitch counts underrepresent the amount of throws an athlete might make. Utilizing throw counts and ratings of perceived exertion may provide more comprehensive assessment of baseball-specific load.

Purpose: To identify the difference in percent change of upper extremity injury risk factors between high, moderate, and low loading groups in collegiate baseball players.

Methods: Shoulder strength and range of motion were assessed every 4 weeks. Internal and external rotation range of motion were combined into total rotation range of motion (TROM). Strength was measured as peak force for internal (IRPF) and external rotation (ERPF). After each practice or training session, participants provided the duration of baseball activity, throw count, and a body-specific and arm-specific rating of perceived exertion. Participants were separated into high, moderate, and low loading groups for each training load variable (arm-specific acute-to-chronic workload ratio (ACWR) and cumulative session rating of perceived exertion (sRPE) and body-specific ACWR and cumulative sRPE). Mixed models were used to assess the difference of

percent change in TROM, IRPF, and ERPF between limbs and load groups (high, moderate, low).

Results: There was no effect of loading group or limb on percent change in TROM or ERPF ($p > 0.05$). There was a significant main effect of body-specific ACWR loading group on percent change in IRPF ($F=6.92$, $p=0.002$), with the moderate loading group demonstrating an 18.21% lower percent change than the high loading group ($p < 0.001$, Cohen's d=0.87). There was no other arm-specific or body specific loading group effects on percent change in IRPF.

Conclusion: Shoulder strength changes differently based on body-specific training load, potentially indicating that body specific load should be collected along with arm-specific load. There were no significant differences in limb, indicating that changes may occur simultaneously rather than independently.

Clinical Relevance: Changes in TROM, ERPF, and IRPF may occur together rather than independently. Body-specific load may need to be collected to understand how baseball participation influences shoulder strength.

Key Words: Baseball, training load, shoulder

Word Count: 348

Introduction

Injuries in baseball primarily affect the shoulder and elbow,[11,92] likely due to the throwing motion, and likely result from both extrinsic participation factors and intrinsic musculoskeletal physical characteristics.[256] Increased participation,[24,55,56,75] limited rest and recovery,[175] and participation despite self-reported tiredness[54,60] have been linked to baseball specific injury, while decreased range of motion[37,40] and strength[41,42,44] have been linked to shoulder and elbow injury in prospective studies. Extrinsic and intrinsic risk factors are likely linked, as increased load from training may influence changes in intrinsic injury risk factors.[155]

Baseball throwing utilizes unique whole-body sequencing, with each proximal segment generating speed for distal segments.[14] This summation of speed allows baseball players to impart high force on the ball but also results in high joint loads on the shoulder.[14–16] These high joint loads, exceeding 1000N of shoulder proximal force,[17–20] require considerable activation of the rotator cuff.[139,150] The rotator cuff must provide dynamic stabilization to prevent excessive force from being placed on non-contractile tissues in the shoulder, such as the glenoid labrum, joint capsule, and subacromial bursa.[139] The cumulative nature of baseball throwing leads to changes in physical characteristics of the rotator cuff, including decreased range of motion,[28,30] decreased strength,[31] changes in muscle morphology,[28,32] and increased self-reported pain and fatigue of the shoulder.[32,33] These changes are similar to laboratory-based muscle fatigue and damage studies,[34,36] and changes seem to return to a baseline state within 3 days of baseball participation.[28,30,32] The repeated nature of baseball throwing causes repetitive microtrauma to accumulate, leading to changes within the

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glenohumeral soft tissue that manifest as changes to strength and range of motion.[32,51] Participation habits are very important to monitor, as excessive throwing or improper recovery may lead to the accumulation of repetitive microtrauma.

Previous literature utilizes pitch counts to quantify load associated with baseball participation,[55,56,60,75] and pitch counts have been associated with injury risk,[75] arm pain,[55] and glenohumeral strength.[155] Unfortunately, recent evidence suggests that simple pitch counts do not accurately represent arm load associated with baseball participation.[195] Zaremski et al.[195] indicates that pitch counts only account for 58% of all throws made in a game by a baseball players. Warm-up throws, bullpen throws, and fielding throws add an additional 42% load that goes unaccounted. Additionally, pitch counts do not account for other baseball sport activities, including fielding, running, hitting, and throwing external to pitching. The emergence of assessing training load with both external (throw counts) and internal loads (rating of perceived exertion (RPE)) have demonstrated significant utility in predicting injury risk in cricket,[65,72] a similar overhead sport to baseball. Load monitoring practices in throwing sports are under developed,[61] but utilizing internal and external loads via session-RPE (sRPE) to quantify baseball specific training load may provide a more comprehensive assessment of baseball-specific load. The implementation and development of sRPE methods would allow for evidence-based participation and rest guidelines. To the authors knowledge, there is currently no literature that utilizes sRPE to quantify baseball participation.

The link between baseball participation and injury is well established[54–56,60,75] and has led to the development of pitching guidelines from USA Baseball.[3] While these guidelines provide recommendation for pitchers, there are no recommendations for

position players or for non-throwing activities. Baseball players, parents, and coaches may benefit from the development of sRPE based training load assessments, as they may provide a more comprehensive assessment of baseball participation. McHugh et al.[155] demonstrated that those who have high external training loads demonstrate significant decreases in shoulder strength, so it can be hypothesized that these results would be similar when utilizing sRPE based measures. Therefore, the purpose of this study is to identify the difference in percent change of glenohumeral range of motion and strength between high, moderate, and low load groups in collegiate baseball athletes over the course of 4 weeks. We hypothesized that there would be a significant interaction of limb and group, indicating that baseball players in the highest loading groups would demonstrate the largest decreases in shoulder strength and range of motion over the course of 4 weeks, but these would only be present in the dominant limb.

Methods and Materials

Research Design

Participants were recruited from two collegiate baseball teams and signed approved Institutional Review board consent forms. Participants were active baseball players who participated in the fall season of their respective teams. Participants were required to be between the ages of 18-25, have access to the training load surveys via a smartphone or computer, and complete all study procedures without pain or discomfort. Exclusion criteria included current pain or injury that limited participation, injury or pain that limited activity within the last 3 months, no previous surgery within the

last year, and no self-reported mental health disorder, including but not limited to anxiety, depression, or mood disorder. A longitudinal repeated measures design was used for the current study. Participants completed a playing and injury history form regarding their baseball experience to ensure that they meet all inclusion and exclusion criteria. Once enrolled, participants completed physical data collection sessions at preseason, 4-week, 8-week, 12-week, and 16-week time points throughout the course of the fall semester to collect glenohumeral rotational range of motion and strength. Participants filled out daily training load surveys on a computer or smartphone device. To qualify for the statistical analysis for this study, participants were required to meet all inclusion and exclusion criteria and answer at least 50% of the training load and well-being surveys from the previous 28 days, to correspond with the cumulative sRPE measures and the chronic component of the ACWR calculation. Once reassessed with these *a priori* rules, the final dataset contained 18 participants who combined for 30 total physical testing sessions (age= 20.1 ± 1.3 years, height=185.0 ± 6.5cm, mass=91.0 ± 10.2kg).

Musculoskeletal Injury Risk Variables Assessment

Glenohumeral Range of Motion

Glenohumeral rotation range of motion was assessed with the subject lying supine with the arm abducted to 90 degrees and elbow flexed 90 degrees. A researcher stabilized the scapula by placing a posteriorly directed force on the coracoid process, and then the researcher rotated the shoulder until terminal internal rotation was reached. A second researcher then aligned a digital inclinometer (Saunders Group,

Chaska, MN, USA) with the forearm and read the measure provided on the digital

inclinometer. External rotation was examined similarly, during passive external rotation

(**Figure 24**). The range of motion assessments were performed 3 times on the dominant

and non-dominant limbs. The average of these three measures were recorded as the

internal rotation and external rotation variables. Internal rotation and external rotation

were summed to obtain the outcome measure of TROM, measured in degrees. Percent

change (Pre-Post/Pre * 100) from the most recent measure was used in the statistical

analyses. This method has been used in previous literature with good reliability and

precision,[90,112,257] and pilot testing established the reliability and precision of TROM with

pilot testing of 20 non-throwing participants ($ICC_{2,3}=0.868$, SEM=4.55°).

Figure 24. Glenohumeral rotational range of motion assessment method.

Glenohumeral Rotational Strength

Shoulder rotational strength assessments were performed using a calibrated

tension load cell (TSD121C Hand Dynamometer, Biopac Systems Inc., Goleta, CA,

USA), a chain, and a padded handle. Participants were asked to lie prone on a plinth

with the shoulder abducted to 90 degrees and elbow flexed to 90 degrees, so the hand

is pointing towards the ground. The participant's humerus laid on the plinth while the forearm was off the table. Padded buttresses were placed anterior and posterior to the humerus to prevent any motion other than internal and external rotation. A chain was secured to a fixed object at a right angle to the participant's forearm. A handle was secured to the other end of the chain, and the participant pulled on the handle during the strength testing. The load cell was placed between the handle and the secured object (i.e. plinth arm) with a carbineer and chain. The participant pulled against the handle and chain for 3 – 4 seconds to determine their maximum (internal and external rotation) isometric strength (**Figure 25**). Participants were given one warm-up trial and then performed at least 2 and up to 3 trials that were recorded. Limb and direction were randomized. All trials were performed in one direction, and the opposite direction were performed following completion. One minute of rest was given between each test. Visual inspection was performed during the trial to ensure the table did not move. Pilot testing was performed on 20 non-throwing participants to determine test-retest reliability and precision of IRPF ($ICC_{2,3}$=0.936, SEM=14.66N) and ERPF ($ICC_{2,3}$=0.935, SEM=11.49N). Previous evidence suggests that handheld dynamometers may introduce bias into testing,[230] as they are often affected by tester size, weight and gender. [231]

Rotational strength data was sampled at 2000 Hz with a Biopac acquisition system (MP150, ACQKnowledge software, Biopac Systems Inc., Goleta, CA, USA). Strength data was reduced offline with custom software (LabView 17.0; National Instruments, Austin, TX, USA) from text files collected during the physical data collection session. Data was filtered via a low pass filter with a cutoff frequency of 50 Hz

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then smoothed with a fourth order zero phase shift Butterworth filter. A 200ms epoch

was used to find the maximum force over the duration of the trial in newtons (N). The

peak 200ms epoch from each trial was utilized to find the average of the three trials of

each strength test. External rotation peak force (ERPF) and internal rotation peak force

(IRPF) were attained from the data reduction procedure, and the percent change in

IRPF and ERPF from the previous test time was used in the data analysis.

Figure 25. Glenohumeral rotation strength assessment method

Training Load Assessment

Training load was collected with the Daily Training Load Assessment Survey

(**Appendix 3**). This survey was developed to feasibly and conveniently collect pertinent

training variables through a computer and smartphone-based application (Qualtrics

LLC, Provo, UT, USA). The Daily Training Load Assessment Survey was collected each

day following activity, and participants were asked to record it within 30 minutes following conclusion of activity. This survey was designed to capture aspects of training load associated with baseball participation. Participants reported the duration of their activity in minutes and the number of throws that they performed during baseball participation for the day. Duration, recorded in minutes, was defined as all aspects of on-field and off-field baseball participation, strength training, and conditioning. A throw was defined as any throw outside of warm-ups, including long toss, flat ground, bullpens, live games, and fielding practice. Previous evidence indicates that throws between 18 meters and 55 meters demonstrate similar joint loads.[138] Throws of over 37 meters also demonstrate joint loads that are similar to baseball pitching.[19] Since these loads are very similar, all throws were equally weighted in this study.

Participants were asked to provide their rating of perceived exertion (RPE) experienced during baseball participation and any current training session, recorded on a scale from 0-10. The Daily Training Load Assessment Survey provided an image for participants to use as a reference to determine their level of exertion. Participants provided RPE with regards to two separate body regions: one regarding total body exertion and one regarding arm specific exertion. RPE was used in this study to quantify the perceived exertion during baseball related training and participation. Previous research has indicated that RPE demonstrates high reliability and validity when compared to heart rate methods of internal load[199] and training impulse.[185–187]

Data from the Daily Training Load Assessment Survey was first reduced into daily total loads. Daily total body sRPE was calculated each day as the product of

baseball specific participation and total body RPE, and daily arm-specific sRPE was calculated each day as the product of throw count and arm-specific RPE.

Given compliance challenges with daily training load and well-being assessments, missing data was present. Data was visualized to ensure that there was no trend in missingness, and then the missing data was handled through multiple imputation techniques.[252–254] This method is preferred over other types of imputation, such as single imputation, closest match, and standard likelihood methods.[253] Multiple imputation replaces missing values with pseudo-random values based on observed values within the dataset for a given individual while maintaining non-missing datapoints within the dataset.[253] The predictive mean matching imputation procedure was performed multiple times on multiple datasets, to enhance the accuracy of the missing data. Twenty-five imputations were performed on 5 datasets, and these multiple datasets were combined to create a single complete output, on which the statistical analyses were performed. To qualify for missing data analysis, the participant was required to have at least 50% responsiveness to 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 to be drawn. Participants with under 50% could lead to inaccurate estimates and biased imputed data. Subject ID, team, date, practice type, and playing position were utilized to impute missing data for the daily arm-specific sRPE and daily body-specific sRPE variables.

Following imputation, four main outcome variables were calculated from the data collected on the Daily Training Load Assessment Survey: 4-week body-specific

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cumulative sRPE, 4-week arm-specific cumulative sRPE, body-specific ACWR, and arm-specific ACWR. To obtain the 4-week body-specific cumulative sRPE, the daily total body sRPE for the 28 days immediately prior to the participant's physical data collection session were summed. To obtain the 4-week arm-specific cumulative sRPE, the daily arm-specific sRPE for the 28 days immediately prior to the participant's physical data collection session were summed. The body-specific ACWR was calculated as the average daily body-specific sRPE of the 7 days prior to the physical data collection session relative to the average daily body-specific sRPE of the 28 days prior to the physical data collection session. The arm-specific ACWR was calculated in a similar manner as the average daily arm-specific sRPE of the 7 days prior to the physical data collection session relative to the average daily total body load of the 28 days prior to the physical data collection session. Similar to previous research,[155] the current study grouped each training load variable (arm-specific ACWR, body-specific ACWR, arm-specific cumulative sRPE, and body-specific sRPE) into high, moderate, and low training load groups. The groups were split into evenly distributed groups with an equal number or cases in each group (n=10).

Statistical Analysis

The difference of percent change in TROM, IRPF, and ERPF between training load groups and limbs load was assessed with a random intercepts linear mixed model. The model utilized subject nested within team as random intercepts, to account for any variance associated with these measures and to account for the multiple cases for some participants. The percent change in TROM, ERPF, and IRPF from the previous physical testing session served as the dependent variable. The independent variables

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were limb and the training load group (high, moderate, low). Separate models were run

for each arm-specific and body-specific ACWR and cumulative sRPE training load

group, leading to four models in total were run for each dependent variable. Interaction

and main effects were deemed significant at $p<0.05$, and all post-hoc testing was

performed with Bonferroni corrections for multiple comparisons (group: $0.05/3 = 0.0133$,

limb: $0.05/2 = 0.025$, group*limb: $0.05/6= 0.0083$). Effect sizes (ES) were calculated for

the interaction and main effects via the variance associated with each fixed effect.

Cohen's d effect sizes were calculated for each pairwise comparison using group

means and standard deviations, and 95% confidence intervals were calculated for each

parameter estimate in the mixed model. All analyses were performed in R.[258]

Results

<u>Descriptive Statistics</u>

The descriptive statistics for training load group are presented in **Table 14**. Arm-

specific ACWR was well distributed, with each group separate by approximately 0.5

arbitrary units (AUs). Body-specific ACWR was slightly more skewed towards lower

values, with the moderate and low group separated by 0.43 AUS and the moderate and

high group separated by 0.6 AUs. The distribution was also very small for the moderate

group, and larger for the high training load group. For the cumulative sRPE values,

there were similar distributions to the ACWR, with the highest groups demonstrating

larger standard deviations and the moderate and low group demonstrating slightly

smaller standard deviations.

Table 14. Descriptive group training load statistics. Data is presented as mean ± SD. All data present in arbitrary units (AUs)

	High			Moderate			Low		
Arm-Specific ACWR	1.62	±	0.41	1.06	±	0.11	0.63	±	0.17
Body-Specific ACWR	1.39	±	0.47	0.79	±	0.04	0.36	±	0.20
4-Week Arm-Specific sRPE	3095.00	±	791.28	1630.00	±	162.81	973.00	±	432.06
4-Week Body-Specific sRPE	25027.59	±	8324.85	12508.22	±	1796.05	6070.20	±	2336.62

Percent Change in TROM

There was no significant interaction between loading group and limb. After accounting for variance due to team and subject, mixed effect modeling did not demonstrate any main effect for limb (F=0.47, p=0.494) or arm-specific (ACWR: F=0.21, p=0.811; sRPE: F=0.16, 0.855) or body-specific (ACWR: F=0.31, p=0.734; sRPE: F=1.13, p=0.329) loading groups. **Figure 26** provides a boxplot of percent change in TROM by limb and loading group.

Figure 26. Percent change in TROM by limb and loading group. A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific sRPE, D) Body-specific sRPE
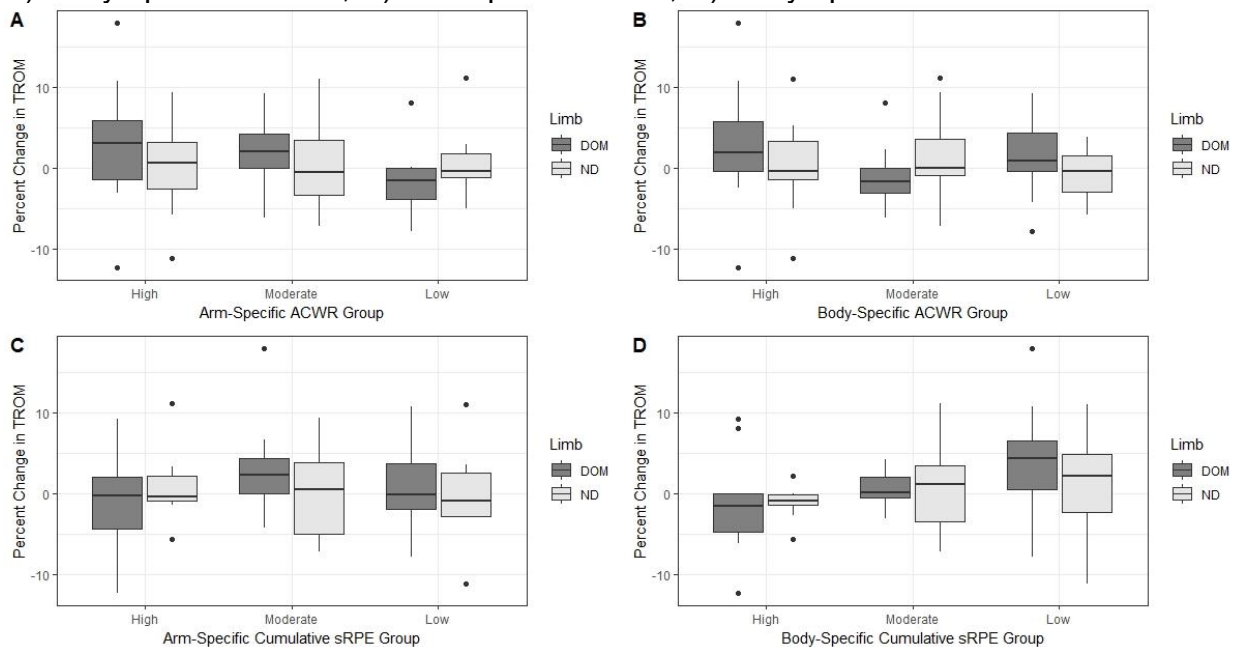
Percent Change in External Rotation Strength

After accounting for team and subject, there was no significant interaction between limb and any training load group. There was no significant main effect of limb (F=0.86, p=0.359) or arm-specific (ACWR: F=0.10, p=0.908; sRPE: F=1.15, p=0.325) variables. There was no significant main effect of body-specific sRPE loading group (F=0.01, 0.9831) but there was a significant main effect of body-specific ACWR (F=3.37, p=0.035, ES=0.47). The moderate loading group demonstrated a 10.4% lower percent change in ERPF than the low loading group (95% CI: 1.65% - 19.25%, p=0.021, Cohen's d=0.65) and an 8.99% lower percent change than the high loading group (95% CI:1.37% - 19.25%, p=0.021, Cohen's d=0.45). After accounting for multiple comparisons (0.05/3=0.0133), there was no significant difference between the loading groups. Effect sizes are moderate to small, indicating a moderate to small magnitude of difference between the groups. **Figure 27** demonstrates differences between limbs and loading groups for each arm-specific and body-specific loading group.
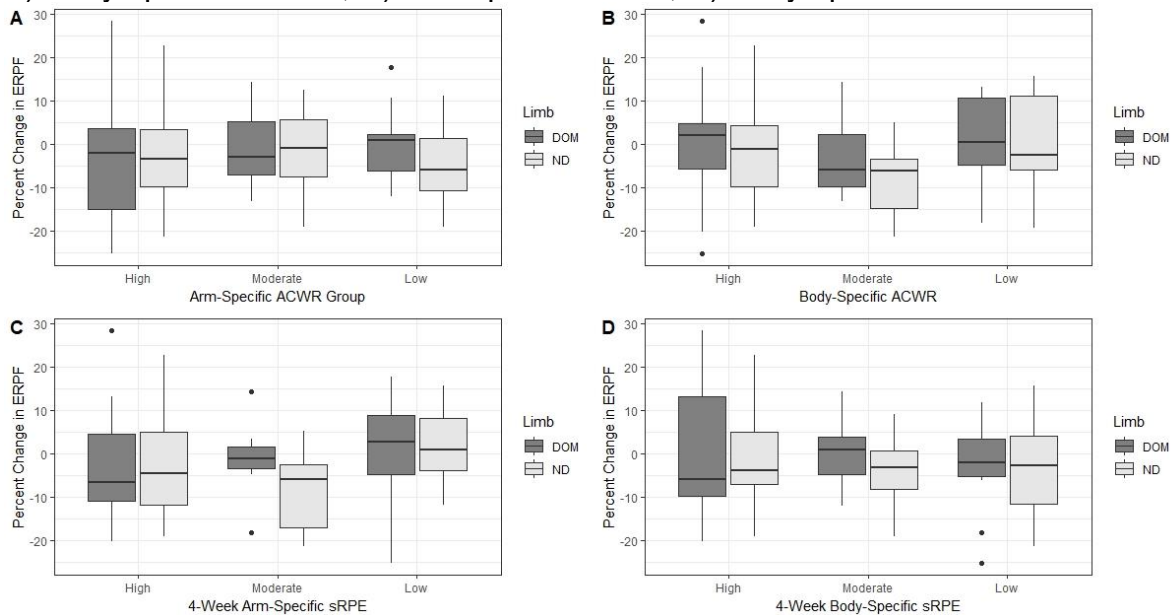
Figure 27. Percent change in ERPF by limb and loading group: A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific sRPE, D) Body-specific sRPE.

Percent Change in Internal Rotation Strength

After accounting for team and subject there was no significant interaction or main effect of limb (F=0.01, p=0.91). There was no significant main effect of arm-specific load group (ACWR: F=1.59, p=0.21; sRPE: F=0.75, p=0.479) or body-specific cumulative sRPE (F=1.11, p=0.337). There was a significant main effect of body-specific ACWR on percent change in IRPF (F=6.92, p=0.002, ES=0.58). Post-hoc testing revealed that the moderate loading group demonstrated an 18.21% lower change when compared to the high loading group (95% CI: 8.32% - 28.10%, p<0.001, Cohen's d=0.87). The moderate loading group also demonstrated a 12.09% lower change when compared to the low loading group as well (95% CI: 1.29% - 22.88%, p=0.029, Cohen's d=0.53), but when accounting for multiple comparisons, there was not a significant effect (p>0.0133). Effect sizes indicate that a large effect of body-specific ACWR group had a moderate

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effect on percent change in internal rotation strength. **Figure 28** graphs the percent change in IRPF across limbs and loading groups.

Figure 28. Percent change in IRPF by limb and loading group: A) Arm-specific ACWR, B) Body-specific ACWR, C) Arm-specific cumulative sRPE, D) Body-specific cumulative sRPE.
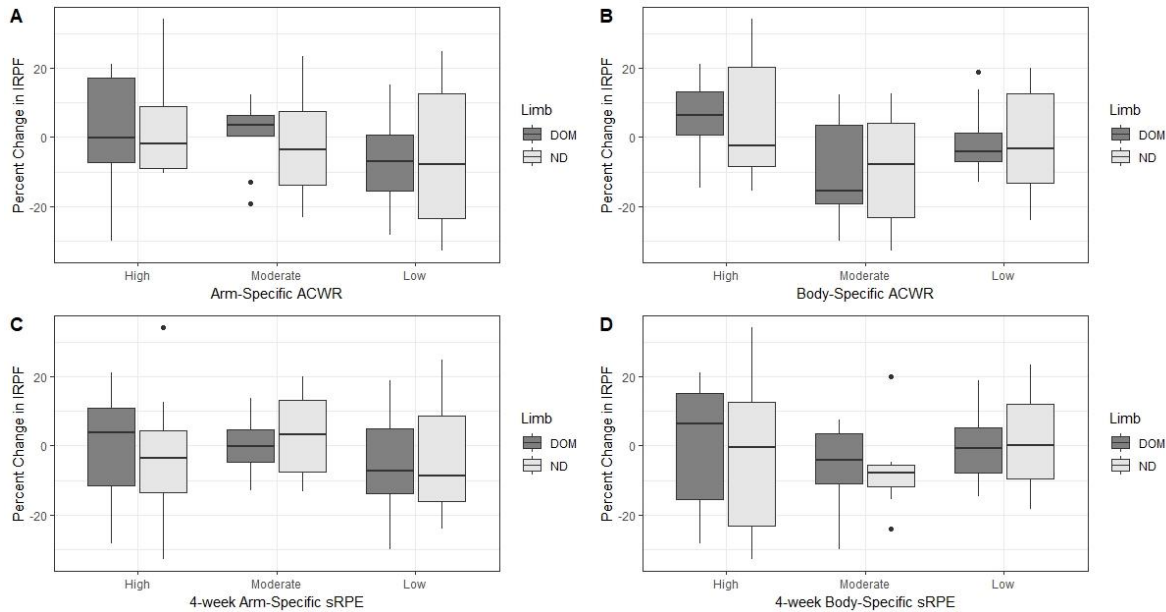

Discussion

The results of the study demonstrate how baseball specific injury risk factors change during times of high, moderate, and low training loads. There was a significant main effect of the moderate loading group for body-specific ACWR, demonstrating that those with a moderate ACWR demonstrated significantly lower percent change in internal rotation strength compared to those with high ACWR. Additionally, there was no significant interaction between the training load groups and limb, and there was no main effect of limb, contrary to our hypothesis. The results seem to indicate that side-to-side differences occurred in tandem, as the dominant and non-dominant limbs demonstrated similar changes. It can be hypothesized that body-specific load may influence shoulder

strength from a systemic, or central, perspective rather incurring local musculoskeletal changes.[26] The results from the current study do not support our hypothesis, but rather indicate that body-specific loads may need further research to better understand their influence on injury risk in baseball athletes.

Previous evidence indicates that amount of participation is implicated in baseball injury, as pitchers who throw over 100 innings[75] or have very high throw counts are at higher risk of injury.[55,56] At a more granular level, McHugh et al. (2016)[155] demonstrated that baseball pitchers who throw over 400 pitches in a season demonstrate significantly more strength loss on their dominant arm than those who throw less than 400 pitches in a season. This previous evidence indicates the effects of baseball participation, primarily external load, on injury risk,[55,56] arm pain,[56] or changes in physical injury risk factors.[155] External load measures only account for 58% of all throws an adolescent baseball players makes in a single game, with the additional throws coming from bullpen, warm-up, and fielding throws.[195] Recent research indicates that external load measures paired with internal load measures may be better indicators of injury risk, as injury risk is highest when ACWR and cumulative sRPE measures were at their highest.[65,70] The current study aimed to apply these sRPE type measures of load monitoring to a sport similar to cricket that is far more popular in America. The results demonstrate that percent change in shoulder TROM, ERPF, and IRPF do not differ across training load groups. It was hypothesized that inclusion of the internal load measures would provide a more comprehensive assessment of load that would be related to injury risk factors. This was not true, as there was no trend in the high, moderate, and low load groups.

Research indicates that ACWR may have an appropriate 'Sweet Spot', meaning that excessively high training loads and excessively low training loads may be predictive of injury, but the loads between them may be protective against injury.[63] Lyman et al. (2001)[56] demonstrated that baseball pitchers who throw over 600 pitches and pitchers who throw under 300 pitches are at a higher risk of arm pain than those who throw between 300-600 pitches per season. Cricket fast bowlers who bowled fewer than 123 overs per week or fast bowlers that bowled over 188 overs per week were at a higher risk of injury than those who bowled between 123-188 overs per week.[70] This evidence aligns with more recent training load assessment research, indicating that athletes who demonstrate ACWRs less than 0.8 AUs of over 1.3 AUs may be in an underloading or overloading state, respectively, and could be at a higher risk of injury.[65,259] The current study did not support the evidence of this optimal loading window., rather, it demonstrated the exact opposite: those in the optimal loading window demonstrated the largest changes. The participants in the moderate body-specific ACWR training load group demonstrated lower percent change in IRPF than the high or the low training load group. While the goal was to distribute participants evenly across groups, similar to previous literature,[155] the descriptive statistics of our training load groups demonstrates that the low and the moderate loading groups more represent the lower end of the ACWR values. Additionally, very few of the cases reached a measure of 1.5 AUs or greater in the current study (n=3). This lack of high values may be due to participant selection, as the convenience sample was recruited from a very controlled fall season, where loads could be prescribed and altered if needed. Future research should assess the physical function when body-specific ACWR data reaches over 1.5 AUs during a

competitive season where loads are more random in nature. Research should be performed on injury risk in baseball athletes to indicate if body-specific load is associated with injury risk in baseball athletes.

Baseball pitching requires significant muscle activation during arm deceleration, and this muscle activity is theorized to cause changes to shoulder range of motion[28] and strength[31] following activity. Evidence suggests that these changes are unilateral and don't affect the non-dominant limb, so the cumulative changes should also only affect the dominant and not the non-dominant limb. The current study indicates that changes to shoulder range of motion and strength occur in tandem, as there is no significant interaction or main effect of limb. Although there was a small time window for changes in this study (4 weeks), McHugh et al. (2016)[155] demonstrated that even when assessing these measures over the course of a year, the dominant and non-dominant limbs demonstrate similar changes. Local muscle fatigue is likely present following a single baseball pitching bout, as changes are present on the dominant limb and not present on the non-dominant limb.[28,31] Long term changes are likely more central fatigue based, as the season long changes are demonstrated in both limbs.[155] The hypothesis that central fatigue plays a role in baseball injury is also supported by Garrison et al. (2015),[164] which demonstrates that baseball players with a UCL tear demonstrate lower rotator cuff strength on both the dominant and non-dominant limbs. Although not explicitly listed as central fatigue, self-reported fatigue is also a risk factor of throwing injury, as baseball players with some level of self-reported fatigue are 7-36 times more likely to be injured than those who report no self-reported fatigue.[54,59,60] Future research should identify the mechanisms behind strength changes in baseball

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athletes, specifically with an eye towards defining fatigue mechanisms. While this study

did not indicate a change between training load groups, understanding what causes

strength changes in both short-term and long-term settings would allow clinicians to

create proper training and recovery guidelines.

The current study is not without limitations. First, recall bias may have played a

role in the training load data. Participants were told to take the training load survey

within 30 minutes after activity, but there was no specific control for this temporal

parameter. Increasing the time after activity may lead to altered RPE scores, as athletes

may have difficulty recalling the perceived difficulty. More objective measures of throw

load, RPE, and duration of activity may be beneficial to limit the recall bias, but the

application of these surveys should continue to be explored, as they are feasible, cost-

effective, and highly customizable to different baseball settings and applications. Future

research should address how to best collect self-reported training load via smartphone

and computer-based training load surveys.

The study population was highly competitive baseball athletes of all positions.

The overall throw loads were equally weighted, with fielding throws, warm-up throws,

long toss, and mound throws all equally weighted, although each may not create similar

forces on the arm.[19,138] Internal load measures were obtained alongside throw counts to

determine external loads, but there is no indication that RPE measures truly reflect

physiological responses in this population. The sport of baseball requires far less

aerobic exertion compared to field sports that utilize sRPE, so sRPE based load

measures may be slightly skewed in a more anaerobic oriented sport. Future research

should identify if sRPE based measures accurately reflect physiological or psychological measures associated with overtraining or increased injury risk.

While previous evidence suggests that throw counts are related to overall injury risk and shoulder strength changes in baseball players, the current study indicates that there is no effect of arm-specific load on percent change in shoulder range of motion or strength. Clinicians, coaches, and sports scientists should consider adding body-specific training load measures to baseball monitoring solutions, as the body-specific ACWR influences percent change in IRPF. Percent change was unaffected by limb, indicating that the changes within the occurred in tandem rather than independently. When monitoring baseball players or creating throwing programs to appropriately prepare baseball players for a competitive season, clinicians should consider both throwing load and overall body load to create a comprehensive program that prevents drastic overloading.

CHAPTER 6: MANUSCRIPT 2

INFLUENCE OF BASEBALL TRAINING LOAD ON CLINICAL REACH TESTS AND GRIP STRENGTH IN COLLEGIATE BASEBALL PLAYERS

Overview

Context: Baseball-specific load might influence strength or range of motion. Clinical reach tests and grip strength are clinical screening tools for shoulder range of motion and strength, so baseball specific training load may influence them as well.

Objective: To determine the difference in glenohumeral reach and grip strength percent change between limb and groups of high, moderate, and low load in collegiate baseball athletes.

Design: Repeated measures

Setting: University athletic training room

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

Main Outcome Measures: Overhead (OHRT) and behind the back-reach tests (BBRT) and grip strength assessments were performed on both the dominant and non-dominant limb every 4 weeks over a fall semester. After each practice or training session, participants recorded duration of baseball activity, number of throws, and a body-specific and arm-specific rating of perceived exertion. Training load groups were created for each loading variable: body-specific acute-to-chronic workload ratio

(ACWR), arm-specific ACWR, body-specific cumulative load, and arm-specific cumulative load. Mixed models were used to assess the difference between loading groups and limbs.

Results: Arm-specific ACWR group demonstrated a main effect for OHRT (F=7.70, p=0.001), BBRT (F=4.01, p=0.029), and grip strength (F=8.89, p<0.001). For OHRT, the moderate loading group demonstrated a 10.8% change higher than the high group (p=0.004) and a 13.2% change higher than low group (p<0.001). For BBRT, the low loading group had an 10.1% change higher when compared to the moderate loading group (p=0.011). For grip strength, the low load group demonstrating 12.1% change higher than the high load group (p=0.006) and 17.7% change higher than the moderate load group (p<0.001).

Conclusions: Arm-specific training load is related to clinical reach tests and grip strength in college baseball players. Monitoring training load during baseball participation may provide information regarding an athlete's physical health.

Key Words: baseball, training load, grip strength

Word Count: 309

Introduction

Baseball injury primarily affects the shoulder and elbow,[11] and is likely the result of the throwing motion. Throwing load is related to injury, as those with the most pitches during a year are at a higher risk of injury.[75] Recent evidence indicates that pitch counts may not be a good measure of load on baseball players, as pitch count only accounts for 58% of all the throws a baseball pitcher makes in a single game.[195] Bullpen and warm-up throws could account for 42% more throwing load, and this load metric does not include non-pitching activities, including throws in the field, hitting, and baserunning. Comprehensive assessments of load are needed in this population to better quantify baseball participation. When utilizing throw counts and rating of perceived exertion to create session rating of perceived exertion (sRPE) load measures, throwing load is related to injury in cricket, a sport similar to baseball.[65] Utilizing both external load, the measure of physical work, and internal load, the physiologic or perceptual response to activity, may provide a more comprehensive assessment of baseball-specific load in baseball athletes.

Throwing a baseball is a total body motion that results in some of the fastest movements in sport, with angular velocities of glenohumeral internal rotation and elbow extension reaching up to 7600 degrees per second and 2400 degrees per second,[19] respectively. This leads to very high joint forces, including 1100N of shoulder proximal force and up to 90Nm of elbow varus torque.[19] To counteract these forces, muscles of the shoulder and elbow must provide dynamic stability to limit the amount of stress placed on the non-contractile tissue.[139] This muscle activity during high velocity contractions can lead to considerable muscle trauma,[35] and this trauma may be present

after throwing bouts, as indicated by changes to glenohumeral strength[31] and range of motion.[28] Consecutive throwing bouts without proper rest and recovery could lead to the accumulation of negative physical changes, thereby leading to increased injury risk due to low glenohumeral range of motion and strength.

Glenohumeral rotational range of motion has been linked to injury in both prospective and retrospective analysis. Previous evidence suggests that glenohumeral rotational range of motion is linked to shoulder injuries,[37,38] and glenohumeral total rotation and flexion range of motion is prospectively linked to elbow injury in baseball players.[40] Low rotational range of motion is present in those with an ulnar collateral ligament injury as well, indicating that limited range of motion at the shoulder is related to elbow injury.[38] Scapular motion is also theoretically linked to injury,[260] despite evidence that scapular dysfunction is not related to injury rates in baseball athletes in prospective studies.[261] Rotational range of motion assessments demonstrate suspect reliability and precision,[221] and quantification of scapular mechanics are often limited to qualitative analysis of video of scapulohumeral rhythm.[261] Recent evidence indicates that behind the back reach tests are reliable assessments[228] and are moderately related to internal rotation range of motion.[262] Behind the back and overhead reach tests are also incorporated into the Functional Movement Screening protocol to assess good and bad movers from a qualitative standpoint for glenohumeral and scapular motion.[263] Reach tests may be clinically useful to assess gross changes to shoulder rotational range of motion and scapular movement.

Shoulder strength has been implicated in injury as well, with baseball players who demonstrate lower shoulder strength are at a higher risk of injury that results in

more than 3 days missed from sport or requires surgery.[41] Glenohumeral strength is also difficult to measure in the clinical setting, as results from handheld dynamometers can be influenced by size, weight, sex, and strength of the tester.[230] Clinically, it may be easier to utilize simple grip strength assessments, and these measures are related to glenohumeral strength.[248] In baseball players grip strength is linked to blood flow of the upper extremity in a provocative position,[249] and is theorized to contribute to medial elbow joint stability.[108]

Clinical measures such as the glenohumeral reach testing and grip strength provide athletic trainers with quick clinical tools that may provide information regarding glenohumeral strength and range of motion of their baseball players, as grip strength is related to upper extremity strength and reach tests are associated with glenohumeral rotational flexibility. Implementation of these measures at regular intervals would be prudent to assess changes in physical factors, but they may miss critical times when training and playing schedules are more grueling. Training load assessments that utilize both internal and external loads 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 provide clinicians with evidence to alter training programs or insert additional rest days when needed. This information can also be used to create evidence-based training programs that provide appropriate playing guidelines with rest prescribed when needed. Therefore, the purpose of this study is to determine the difference in glenohumeral reach and grip strength percent change between limbs and groups of high, moderate, and low load in collegiate baseball athletes. We hypothesize that there will be

significantly lower percent change in the high loading group compared to the low and moderate loading groups.

Methods

Research Design

Participants were recruited from two collegiate baseball teams and were active baseball players that participated in the fall season of their respective teams. Participants must have been between the ages of 18-25, have access to the training load surveys via a smartphone or computer, and complete all study procedures without pain or discomfort. Exclusion criteria included current pain or injury that limited participation, injury or pain that limited activity within the last 3 months, no previous surgery within the last year, and no self-reported mental health disorder, including but not limited to anxiety, depression, or mood disorder. A longitudinal repeated measures design was used for the current study. Participants completed a playing and injury history form regarding their baseball experience to ensure that they meet all inclusion and exclusion criteria. Once enrolled, participants completed physical data collection sessions at preseason, 4-week, 8-week, 12-week, and 16-week time points throughout the course of the fall semester to collect glenohumeral rotational range of motion and strength. Participants filled out daily training load surveys on a computer or smartphone device. To qualify for the statistical analysis for this study, participants were required to meet all inclusion and exclusion criteria and answer at least 50% of the training load and well-being surveys from the previous 28 days, to correspond with the cumulative sRPE measures and the chronic component of the ACWR calculation. Once re-

assessed with these a priori rules, the final dataset contained 18 participants that combined for 30 total physical testing sessions (age= 20.1 ± 1.3 years, height=185.0 ± 6.5cm, mass=90.9 ± 10.2kg).

Physical Assessments

Glenohumeral Reach Test

Glenohumeral reach tests were performed with the participant standing in an upright erect position. A tape measure ran down 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 non-test arm on the same hip while researchers test the opposite arm. For the behind the back reach test (BBRT), the individual was instructed to place the dorsal side of their hand at the level of their sacrum, make a thumbs up, and then slide the arm up the spine until they reach their maximal distance. Once they reached the maximal distance, the researchers recorded in centimeters where their thumb was located on the tape measure (**Figure 29**). This test was performed 3 times on the dominant and non-dominant limb. The average of the 3 measures was recorded as the BBRT measure. For the overhead reach test (OHRT), the participant will be in the same position as the BBRT, with the participant standing in an upright and erect posture with the arm not being tested resting on the hip, and the origin of the tape measure secured to the most prominent portion of the C7 spinous process. The participant was instructed to place the hand of the test limb on their head and begin sliding their hand inferiorly down their spine until they cannot reach any further. Once they have reached the terminal distance, researchers recorded in centimeters where their middle finger is on the tape measure (**Figure 29**). If they are

unable to reach C7, then the measure was recorded as negative from C7. For the

OHRT, higher numbers indicated the participant was able to reach further, and the for

the BBRT, lower numbers indicated the participant was able to reach further. This test

was performed 3 times on the dominant and non-dominant limb. The average of the 3

measures was recorded as the OHRT measure. The percent change from the most

recent testing time was calculated and used for the statistical analyses for both the

BBRT and the OHRT. Pilot tests were performed to obtain the test-retest reliability and

precision of OHRT ($ICC_{2,3}$=0.959, SEM=1.35cm) and the BBRT ($ICC_{2,3}$=0.0.915,

SEM=1.35cm).

Figure 29. Functional reach test assessment method. Left: Overhead Reach Test. Right: Behind the Back Reach Test
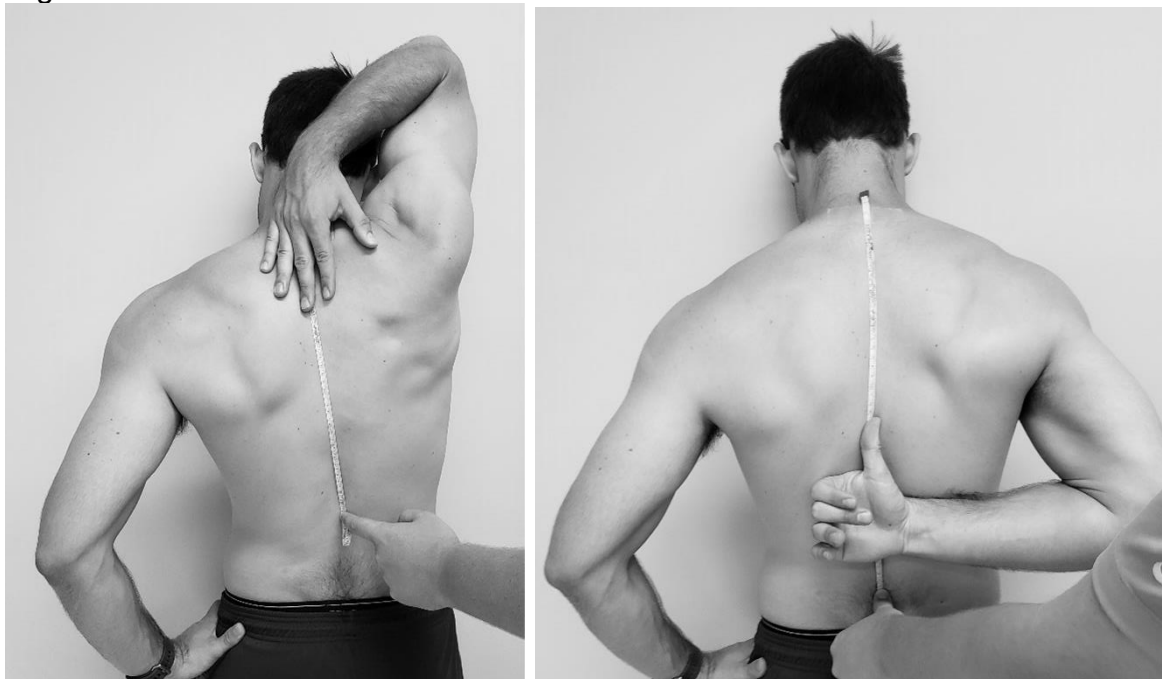
Grip Strength

Grip strength assessments were performed with a handheld compression load

cell (TSD121C Hand Dynamometer, Biopac Systems Inc., Goleta, CA, USA) with

methods similar to Horsley et al. (2016).[248] For the grip strength assessments,

participants performed maximal grip strength trials in 3 different postures: shoulder in

neutral and elbow flexed to 90 degrees, shoulder abducted to 90 degrees and elbow

flexed to 90 degrees, and shoulder abducted 90 degrees, externally rotated 90 degrees

and elbow flexed 90 degrees (**Figure 30**). Previous evidence suggests that blood flow is

correlated to grip strength in the full abducted and externally rotated position, so we

elected to use 3 separate postures for this assessment.[249] Participants stood with their

heels, buttocks, shoulders, head and elbow against a wall for all the grip strength

assessments. Participants performed a single trial in each posture, and the average of

these measures was used for data analysis. Grip strength data was sampled at 2000 Hz

with a Biopac acquisition system (MP150, Biopac Systems Inc., Goleta, CA, USA), and

raw voltage was exported as a text file on a personal computer. Pilot testing was

performed to establish test-retest reliability ($ICC_{2,3}=0.936$) and precision (SEM=14.66N)

of the grip strength assessment.

Grip strength data was sampled at 2000 Hz with a Biopac acquisition system

(MP150, ACQKnowledge software, Biopac Systems Inc., Goleta, CA, USA). Strength

data was reduced offline with custom software (LabView 17.0; National Instruments,

Austin, TX, USA) from text files collected during the physical data collection session.

Data was filtered via a low pass filter with a cutoff frequency of 50 Hz then smoothed

with a fourth order zero phase shift Butterworth filter. A 200ms epoch was used to find

the maximum force over the duration of the trial in newtons (N). The peak 200ms epoch

from each trial was utilized to find the average of the three trials of each strength test.

Grip strength was attained from the data reduction procedure, and the percent change

in grip strength from the previous test time was used in the data analysis.

Figure 30. Grip Strength assessment postures.

<u>*Training Load Assessment*</u>

Training Load was assessed via a survey developed to feasibly and conveniently

collect pertinent training variables through a computer and smartphone-based

application (Qualtrics LLC, Provo, UT, USA). The training load assessment survey was

collected each day following 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 that they performed during baseball

participation for the day. Duration, recorded in minutes, was defined as all aspects of

on-field and off-field baseball participation, strength training, and conditioning. A throw

was defined as any throw outside of warm-ups, including long toss, flat ground,

bullpens, live games, and fielding practice. Throws of over 37 meters demonstrate joint

loads that are similar to baseball pitching.[19] Since these loads are very similar, all throws were equally weighted in this study.

Participants were asked to provide their rating of perceived exertion (RPE) experienced during baseball participation and any current training session, recorded on a scale from 0-10, with 0 representing a rest state and 10 representing maximal exertion. The survey provided an image for participants to use as a reference to determine their level of exertion. Participants provided RPE with regards to two separate body regions: one regarding total body exertion and one regarding arm specific exertion. RPE was used in this study to quantify the perceived exertion during baseball related training and participation. Previous research has indicated that RPE demonstrates high reliability and validity when compared against heart rate methods of training impulse.[186,187]

Data from the Daily Training Load Assessment Survey was first reduced into daily total loads. Daily total body sRPE was calculated each day as the product of time and total body RPE, and daily arm-specific sRPE was calculated each day as the product of throw count and arm-specific RPE.

Given compliance challenges of the daily collection, missing data existed within the data. Data responsiveness was plotted by day to ensure that this data was completely missing at random, and then missing data was handled through multiple imputation techniques.[254] This method is preferred over other types of imputation, such as single imputation, closest match, and standard likelihood methods.[253] Multiple imputation replaces missing values with pseudo-random values based on observed values within the dataset for a given individual while maintaining non-missing datapoints

within the dataset.[253] The predictive mean matching imputation procedure is performed multiple times on multiple datasets, to enhance the accuracy of the missing data. To qualify for missing data analysis, the participant must have had at least 50% responsiveness to 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 the results would be drawn. Participants with under 50% could lead to inaccurate estimates and biased imputed data. Twenty-five imputations were performed on 5 datasets, and these multiple datasets were combined to create a single complete output, on which the statistical analyses were performed. Subject ID, team, date, practice type, and playing position were utilized to impute missing data for the daily arm-specific sRPE and daily body-specific sRPE variables.

Following imputation, four 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, the daily total body sRPE for the 28 days immediately prior to the participant's physical data collection session was added together. To obtain the 4-week arm-specific cumulative sRPE, the daily arm-specific sRPE for the 28 days immediately prior to the participant's physical data collection session were added together. The body-specific ACWR was calculated by taking the average daily body-specific sRPE of the 7 days prior to the physical data collection session and dividing it by the average daily body-specific sRPE of the 28 days prior to the physical data collection session. The arm-specific ACWR was

calculated in a similar manner: taking the average daily arm-specific sRPE of the 7 days prior to the physical data collection session divided by the average daily total body load of the 28 days prior to the physical data collection session. Similar to previous research,[155] the current study grouped each training load variable (arm-specific ACWR, body-specific ACWR, arm-specific cumulative sRPE, and body-specific sRPE) into high, moderate, and low training load groups. Groups were divided evenly with 10 participants in each group, and the training load groups were used as the independent variables in the statistical analysis.

Statistical Analysis

The difference of percent change in OHRT, BBRT, and grip strength between training load groups and limbs load was assessed with separate random intercepts mixed models. The model utilized subject as random intercepts, to account for subject re-entry into the analysis. The percent change in OHRT, BBRT, and grip strength from the previous physical testing session served as the dependent variable. The fixed effects were limb and the training load group (high, moderate, low). Separate models were run for each arm-specific and body-specific ACWR and cumulative sRPE training load group. Four models in total were run for each dependent variable. Interaction and main effects were deemed significant at $p < 0.05$, and all post-hoc testing was performed with Bonferroni corrections for multiple comparisons. Cohen's f effect sizes (ES) were calculated for the interaction and main effects via the variance associated with each fixed effect. Cohen's d effect sizes were calculated 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.

Results

<u>*Descriptive Statistics*</u>

The descriptive statistics for training load group are presented in **Table 1**. Arm-specific ACWR was well distributed, with each group separated by approximately 0.5 arbitrary units (AUs). Body-specific ACWR was well-distributed across groups, with the differences between the low, moderate, and high training load groups being small. Within the body-specific ACWR, the moderate group demonstrated much smaller overall variance compared to the high and the low group. For the cumulative sRPE values, there were similar distributions to the ACWR, with the highest groups demonstrating larger standard deviations and the moderate and low group demonstrating slightly smaller standard deviations.

Table 15. Descriptive group training load statistics. Data is presented as mean ± SD. All data present in arbitrary units (AUs)

	High			**Moderate**			**Low**		
Arm-Specific ACWR	1.62	±	0.41	1.06	±	0.11	0.63	±	0.17
Body-Specific ACWR	1.39	±	0.47	0.79	±	0.04	0.36	±	0.20
4-Week Arm-Specific sRPE	3095.00	±	791.28	1630.00	±	162.81	973.00	±	432.06
4-Week Body-Specific sRPE	25027.59	±	8324.85	12508.22	±	1796.05	6070.20	±	2336.62

<u>*Overhead Reach Test*</u>

There was no significant interaction for any of the arm-specific or body-specific training load variables. There was a main effect of arm-specific ACWR group on percent change in OHRT (F=7.70, p=0.001, ES=0.61). After accounting for subject as a random intercept, pairwise comparisons indicated the moderate load group demonstrated a 10.8% change higher than the high load group (95% CI: 3.5% - 18.1%, p=0.004, Cohen's d=1.04), and a 13.2% change higher than the low load group (95% CI: 6.1% -

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20.2%, p<0.001, Cohen's d=1.05). There was a main effect of arm-specific cumulative

sRPE on percent change in OHRT (F=4.50, p=0.017, ES=0.48). The low load group

demonstrated a 10.7% change lower in OHRT compared to the high load group (95%

CI: 3.1% – 18.2%, p=0.006, Cohen's d=0.856). There was a main effect of body-specific

cumulative sRPE training load group on percent change in OHRT (F=3.49, p=0.041,

ES=0.40). When comparing group means, the high training load group demonstrated a

9.9% change higher in OHRT compared to the low training load group (p=0.012,

Cohen's d=0.847). There was no main effect of limb (F=0.10, p=0.757) or training load

group (F=0.07, p=0.930) for body-specific ACWR on percent change in OHRT. **Figure

31** represents the percent change in OHRT by loading group and limb for each training
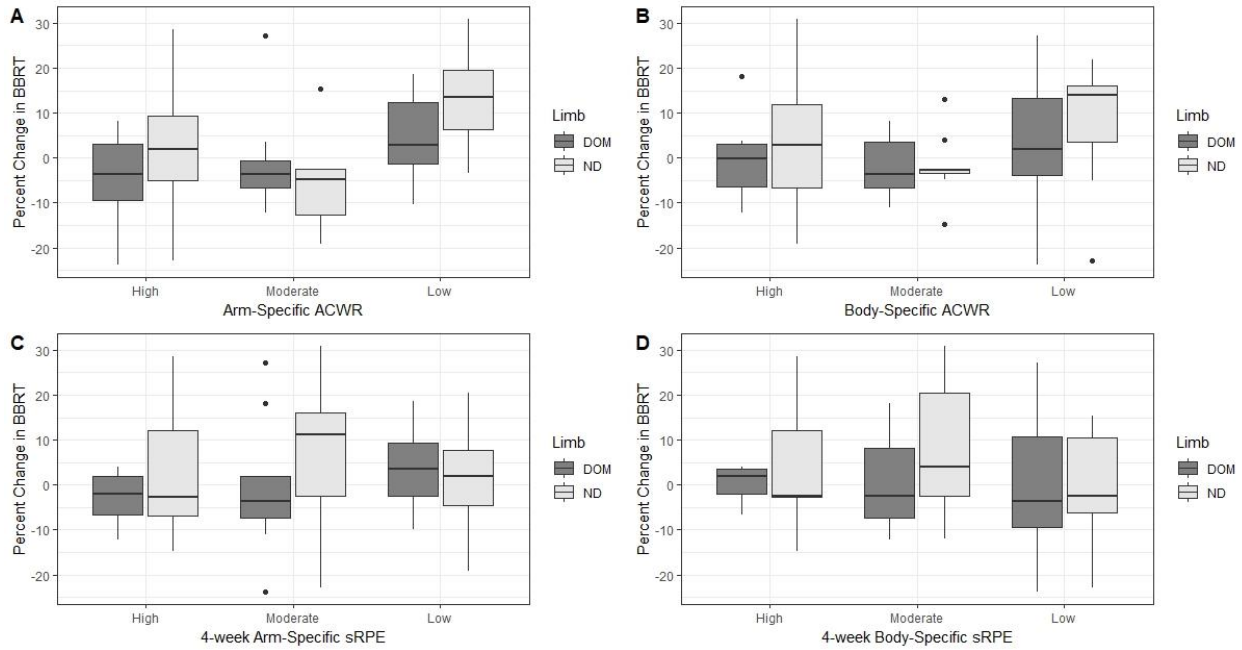
load variable.

Figure 31. Percent change in Overhead Reach Test by loading group and by limb. (A)
Arm-specific ACWR, (B) Body-specific ACWR, (C) Arm-specific cumulative sRPE, (D)
Body-specific cumulative sRPE.\
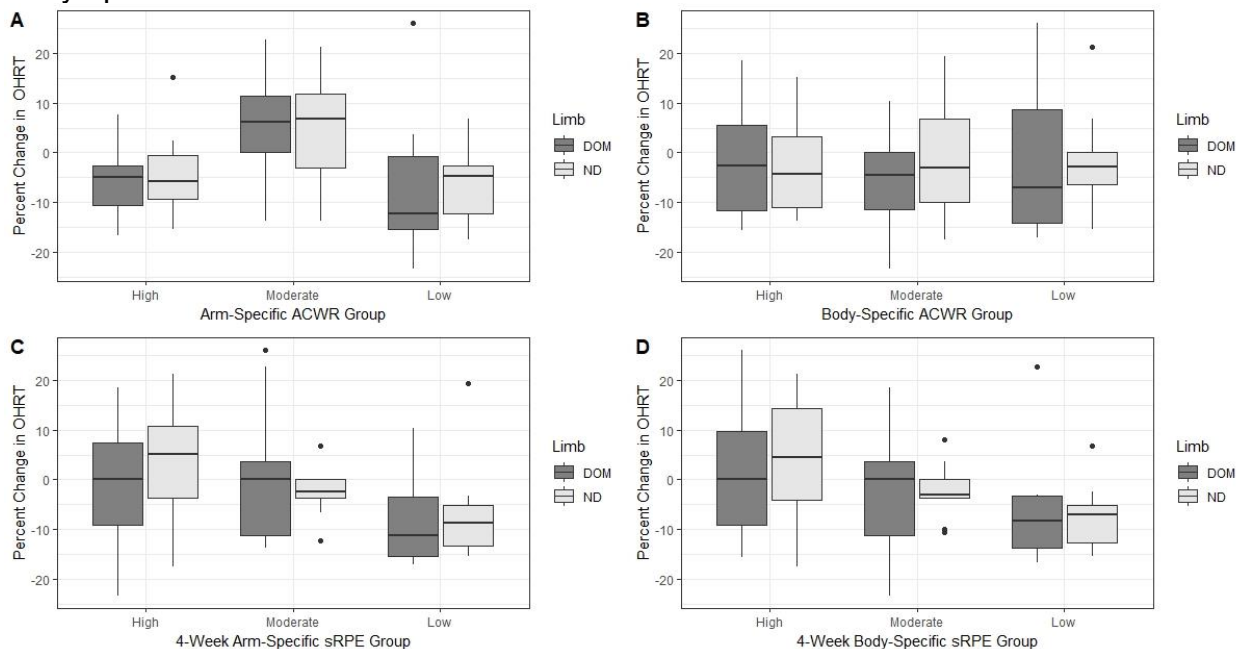
Behind the Back Reach Test

There was a significant main effect of arm-specific ACWR on percent change in BBRT (F=4.67, p=0.014, ES=0.45). After accounting for subject as a random intercept, pairwise comparisons revealed that the low loading group had a 10.1% higher change when compared to the moderate loading group (95% CI: 2.4% - 17.7%, p=0.011, Cohen's d=1.08). There was a difference of 8.9% between the low loading group and the high load group that approached significance, but after accounting for the multiple comparisons, this was statistically insignificant (95% CI: 1.55% - 16.0%, p=0.017, Cohen's d=0.87). A significant main effect of body-specific cumulative sRPE was present on percent change in BBRT (F=4.94, p=0.011, ES=0.53). After accounting for subjects, the low group demonstrated an 11.7% lower change when compared to the moderate group (95% CI: 4.1% - 19.3%, p=0.001, Cohen's d=0.31), but the effect size of this comparison indicates that there may not be a large clinical significance. There was no significant main effect of limb (F=1.73, p=0.197), arm-specific cumulative sRPE training load group (F=0.23, p=0.793), or body-specific ACWR training load group (F=2.71, p=0.076) on percent change in BBRT. **Figure 32** represents the percent change in BBRT by loading group and limb for each training load variable.

Figure 32. Percent change in BBRT by loading group and limb. (A) Arm-specific ACWR, (B) Body-specific ACWR, (C) Arm-specific cumulative sRPE, (D) Body-specific cumulative sRPE.


Grip Strength

There was no significant interaction effect between limb or loading group for any of the training load variables on the percent change in grip strength (p=0.67-0.61). There was a significant main effect of arm-specific ACWR training load group on percent change in grip strength (F=8.89, p<0.001, ES=0.77). Pairwise comparisons of the parameter estimate of the loading groups indicated that the low load group demonstrated a 17.7% higher change compared to the moderate group (95% CI: 3.5% - 20.6%, p=0.006, Cohen's d=0.48) and a 12.1% higher change when compared to the high loading group (95% CI: 3.5% - 20.6%, p<0.001, Cohen's d=0.69). There was no significant effect of limb (F=0.14, p=0.71), arm-specific cumulative load group (F=0.23, p=0.796), body-specific ACWR group (F=1.86, 0.166), or body-specific cumulative load

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(F=0.29, p=0.744) on percent change in grip strength. **Figure 33** represents the percent

change in grip strength by loading group and limb for each training load variable.

Figure 33. Percent change in grip strength by loading group and limb. (A) Arm-specific ACWR, (B) Body-specific ACWR, (C) Arm-specific cumulative sRPE, (D) Body-specific cumulative sRPE.
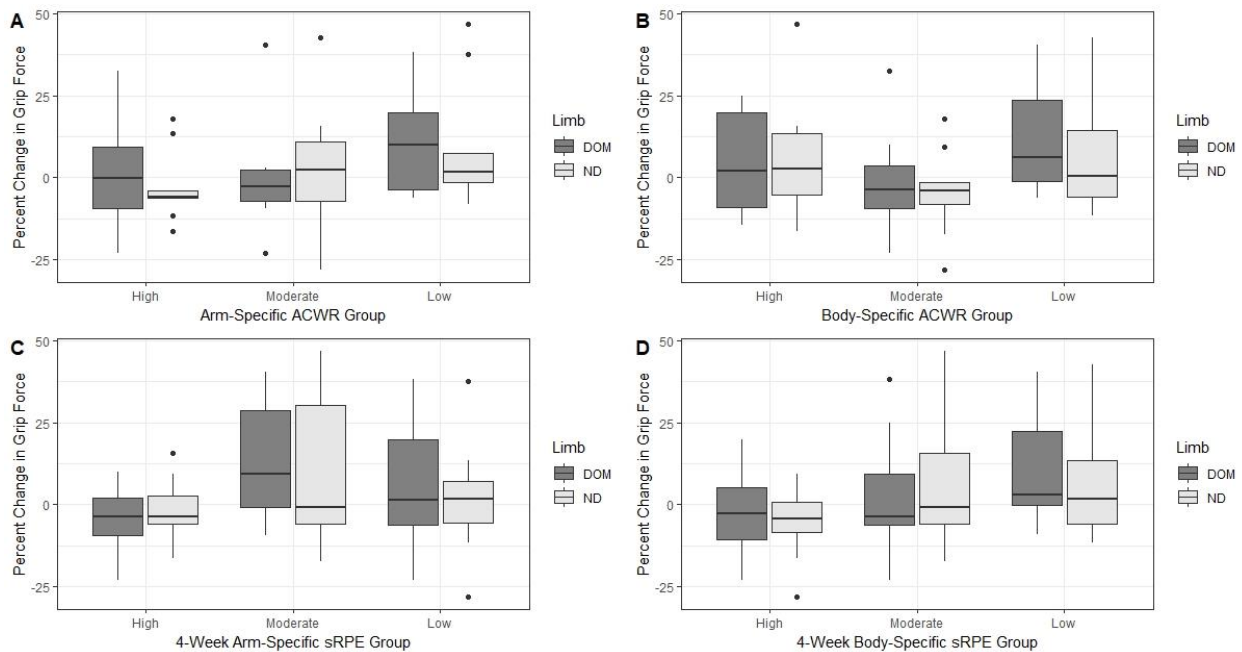
Discussion

The results from the current study indicated the arm-specific ACWR grouping

variable was a significant main effect for all three clinical measures of strength and

range of motion. For the OHRT, the moderate group demonstrated the most positive

changes compared to the low and high loading groups. This result matches with

previous research in load monitoring that indicates a potential 'sweet spot' may exist,

where athletes are participating in sport at an appropriate level that is not too high and

not too low.[63] For the BBRT, the low loading group demonstrated the most negative

change, as lower scores on the BBRT correspond with higher internal rotation scores.[262] Percent change in grip strength was the highest in the low loading group, indicating that grip strength improves when arm-specific load is lower in the current week compared to the previous four weeks. While the reach tests did demonstrate significant differences between body-specific cumulative load groups and arm-specific load, there was no consistent trend across all dependent variables, potentially indicating that these variables may change as a result of non-baseball related activity. The evidence in the current study suggests that arm-specific ACWR is related to clinical measures of range of motion and grip strength, potentially indicating the clinical usefulness of this training load variable.

Injury in baseball players is likely caused by the amount of baseball participation and the application of the baseball participation. While high pitch counts in baseball players have been linked to arm pain[55] and changes in shoulder strength,[155] more recent research demonstrates that pitch counts only account for 58% of the throwing load in a given game, with the extra 42% coming from warm-up throws, bullpen throws, and fielding throws.[195] This also leaves out the effect of weight training, arm care exercises, and sport-specific training, all of which may influence injury risk in baseball players. Quantifying load with both external loads, the physical work of training, and internal loads, the perception or physiological response to training, demonstrates significant utility in predicting injury in cricket, an overhead sport similar to baseball.[65] The current study utilized the sRPE type 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 training group was a main effect on

each of the dependent variables, indicating that the arm-specific ACWR variable may be a useful variable moving forward to quantify baseball participation. The measurement quantified both the total amount of throws made by participant, and the internal perception of difficulty, assessed via an arm-specific RPE. This assessment technique may provide a more comprehensive assessment of baseball participation and could be used as an overhead athlete load monitoring model. Future research should continue to utilize and develop this method, and research should assess how this method might predict injury in baseball players.

Previous evidence demonstrates that low shoulder range of motion is implicated in throwing injury in baseball athletes.[37,38] Low internal and external rotational range of motion have been implicated in elbow[38] and shoulder injuries.[37] Although scapular mechanics are not prospectively linked to injuries in baseball players,[261] there is still a theoretical link between scapular characteristics and injury in overhead athletes.[260] The throwing motion significantly taxes the glenohumeral joint and the scapulothoracic articulation, leading to a change in rotator cuff range of motion[28]. This muscle stress induced from baseball throwing is likely present in multiple muscles about the shoulder region. The OHRT and BBRT are gross assessments of shoulder physical function, and incorporate movements at the humeroulnar joint, glenohumeral joint, and the scapulothoracic articulation. Previous evidence indicates that the BBRT is related to internal rotation range of motion,[262] but there is minimal evidence to indicate the link between OHRT 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 lower reach outcome in the OHRT. This study

demonstrates that there is a change in OHRT between the moderate and low loading

groups and the moderate and high loading groups, but the source of these changes is

not clear. We hypothesized that the change in OHRT in the present study is a collection

of glenohumeral and scapulothoracic changes, but this is purely a hypothesis and was

not investigated in this study. Future research should study the OHRT in more detail to

understand whether changes in the OHRT outcome corresponds to changes in

humeroulnar, glenohumeral, or scapulothoracic range of motion.

Grip strength is critical to protecting the medial elbow joint in baseball athletes.

Baseball pitching creates elbow valgus loads of over 90Nm,[19] but the ultimate failure

point of the ulnar collateral ligament is 36Nm.[106] The dynamic contribution of the medial

forearm muscles is critical to provide an internal varus moment that counteracts the

elbow valgus load during throwing.[108] Grip strength was used in the current study to

assess the strength of the medial forearm musculature, and the results indicated that

grip strength demonstrated the highest percent change in the lowest loading group. This

information could be useful for repeated clinical assessments. If baseball players

demonstrate low grip strength measures, coaches and clinicians may want to consider

the recent load of athletes to determine if they are demonstrating a high, moderate, or

low arm-specific ACWR training load. Decreasing the acute load may be beneficial to

allow grip strength measures to increase. Clinicians may also consider the results of this

study when creating throwing programs for those returning to pitching following injury or

preparing for a competitive period. Building fitness with short windows of moderate arm-

specific ACWR may be beneficial to allow grip strength to increase during a throwing

program. Appropriately prescribing throwing load in this manner will hopefully decrease early season injuries, when injury rates are highest in high school baseball players.[92]

The use of the clinical measures in the current study is critical for athletic trainers that work with many athletes. The methods presented in this research study are reliable,[228] clinician friendly, time efficient and comparable to rotational range of motion measures.[262] Additionally, there is some face validity to the reach tests, as they require motion at the glenohumeral joint and scapulothoracic articulation to attain a maximal distance. A major benefit of all three assessment methods presented in this paper are there is little influence of tester subjectivity on the outcome measures. Traditional rotational range of motion assessments require clinician expertise to determine the appropriate amount of overpressure and stabilization.[221] This can lead to suspect reliability, making the determination of clinical meaningfulness very difficult. The drawbacks to the reach tests and grip strength are that they are not linked to injury risk but only theorized to contribute to injury. Despite these drawbacks, reach tests and grip strength assessments may be able to provide utility as quick screening tools to determine when baseball players demonstrate negative changes. If negative changes are present on these clinical assessments, clinicians may be able to use further physical examination to determine if an athlete requires therapeutic exercise intervention.

There are limitations in the current study. The sample was a convenience sample of collegiate baseball players that were competing in the fall season that consisted of both position players and pitchers. Collegiate baseball players only participate on one team and have a dedicated strength and conditioning coach and athletic trainer. Future research should be performed in younger athletes that play on multiple teams and don't

have the available resources, as they may react differently at higher training loads. Baseball athletes were to respond to the training load survey within 30 minutes following activity, but there was no control for this temporal parameter. Recall bias may have played a role in training load reporting, so future research should identify the best methods for using smartphone and computer-based training load assessments.

Conclusions

Arm-specific ACWR demonstrates a significant effect on shoulder reach tests and grip strength changes in collegiate baseball players, so future training load assessments in baseball may want to consider arm-specific training loads when attempting to quantify baseball training load. The of sRPE measures are also recommended, as incorporating 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 to determine when baseball participation may be too high for a specific baseball player.

CHAPTER 7: MANUSCRIPT 3

BASEBALL SPECIFIC LOAD INFLUENCES SUBJECTIVE READINESS, STRESS, AND SORENESS INTENSITY IN COLLEGIATE BASEBALL ATHLETES

Overview

Background: Subjective well-being is influenced by training load in field sports and professional athletes. It is unclear how training load influences subjective well-being in collegiate athletes or in overhead sports where unique load is being applied.

Hypothesis: High arm-specific and body-specific training loads will influence self-reported well-being in collegiate baseball athletes.

Study Design: Repeated Measures

Level of Evidence: Level 3

Methods: Collegiate baseball athletes (n=19, age = 20.1±1.3 years) were monitored over the course of a fall semester. Prior to training, participants provided self-reported measures of readiness, stress, fatigue, and soreness. Following training, participants provided duration of activity, throw count, body-specific rating of perceived exertion, and arm-specific rating of perceived exertion. Training load was reduced into body-specific acute-to-chronic workload ratio (ACWR) and cumulative load (sRPE) and arm-specific ACWR and cumulative sRPE. Linear and polynomial mixed models evaluated the influence of training load variables on subjective well-being, with subjects, time, and team probed as random intercepts.

Results: There was a significant linear relationship between average weekly readiness and arm-specific cumulative sRPE (F=4.06, p=0.04) and body-specific cumulative sRPE (F=5.91, p=0.02). There was no significant linear relationship between training load and fatigue. There was a significant linear association between average weekly stress and arm-specific ACWR (F=5.03, p=0.03), arm-specific cumulative sRPE (F=16.07, p<0.01), and body-specific ACWR (F=6.92, p=0.01). There was a non-linear relationship between average weekly soreness intensity and arm-specific ACWR (F=6.68, p=0.01) and body-specific ACWR (F=22.57, p<0.01).

Conclusions: Baseball specific measure of training load influence subjective measures of well-being. Load monitoring should be sport specific to ensure that pertinent training load measures are being collected.

Clinical Relevance: Monitoring training load may assist clinicians in identifying when negative well-being changes are present in athletes. Subjective well-being measures may be able to corroborate when negative changes occur as a result of baseball participation.

Word Count: 298

Introduction

        Baseball athletes develop strength, power, endurance, and physical skill through physical training that may result in overreaching. Overreaching is a short-term negative change to sport performance that often occurs concurrently with short-term negative changes to physical characteristics and subjective well-being outcomes.[255] Overreaching can be further broken down into functional and non-functional overreaching. Functional overreaching is a short-term decrement in performance or physical outcomes with an appropriate and planned recovery period.[255] In baseball, functional overreaching may be potentially demonstrated as decrements in physical factors, including glenohumeral range of motion and strength,[28,29,31] following baseball participation. While previous evidence demonstrates that these variables return to baseline levels in the days following activity,[28,30] participation prior to full recovery could lead to cumulative negative changes. Consistent negative changes such as this could lead to non-functional overreaching syndrome, characterized by negative changes in performance for a prolonged period of time.[255] Functional and non-functional overtraining are associated with negative changes in subjective variables as well, including stress, fatigue, and ratings of recovery.[192,255,264]

        When an athlete is overreaching or overtraining, it is common to see significant changes to subjective well-being measures. Brink et al. (2014) demonstrate that scores of general stress are higher, and scores of physical recovery are lower in soccer athletes 2 months prior to experiencing non-functional overreaching.[255] Recent evidence suggests that subjective well-being variables may be more associated with increases in acute training loads and ongoing training.[210] Specifically, measures of stress and fatigue

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from the Recovery-Stress Questionnaire decrease following acute increases in training load, indicating higher stress and fatigue.[214,215] Raeder et al. (2016)[237] demonstrated significant decreases to perceived recovery and stress when participants were purposefully placed in an overreaching weight lifting program. Variables linked to stress demonstrated significant increase and variables linked to recovery demonstrated significant decrease following a 100% increase in training load in competitive rowers.[214] A link between training load and subjective well-being seems to be present, but there is also a link between more objective measures of stress and fatigue. Jurimae et al. (2004)[214] demonstrated a significant relationship between fatigue and training load, as well as a relationship between fatigue and cortisol levels. The association between blood biomarkers and self-reported variables could allow subjective fatigue levels to be used as a proxy to monitoring physiological changes within the body.

Previous evidence exhibits a potential link between subjective reports of well-being and diagnoses of illness or injury. Negative measures of subjective well-being are often present at times of illness and injury.[177] Watson et al. (2017)[202] indicated that daily mood was a significant predictor of injury in youth soccer athletes, and Laux et al. (2015)[211] indicated that fatigue is significantly associated with injury risk in professional football athletes. Physical stress and psychosocial stress are elevated in athletes prior to injury, and decreased perceptions of recovery were related to the occurrence of illness.[192] Finally, performance variables are also related to well-being, as self-reported fatigue, stress, and muscle soreness accounted for 72% of the variance when predicting the change in competitive swimmer's time-trial performance.[216] Measures of stress were also significantly associated with higher game statistics in Australian football.[217]

Previous evidence suggests that sport specific training can have considerable effects on subjective well-being, including psychological and emotional stress[177,210–212] and feelings of fatigue and tiredness.[177,210] Subjective surveys, such as the Profile of Mood States[208,209] and the Recovery-Stress Questionnaire for Athletes[211–213] have been used to quantify changes from activity in these multidimensional constructs, but these assessment tools are not feasible to utilize each day, as they require considerable time to complete. To track subjective well-being over time, recent evidence suggests using simple Likert scales of stress, fatigue, and soreness to track daily well-being, as these outcomes are linked to illness and injury.[202] Baseball is a unique sport with a large upper extremity component, so assessing how baseball participation influences subjective scores in this population require novel assessment methods. There is limited evidence to indicate how baseball sport participation influences subjective scores that have previously been linked to injury and illness. Therefore, the purpose of this study is to determine how baseball participation influences subjective well-being in collegiate baseball athletes. A secondary purpose of this study is to determine how time from the beginning of the semester influences subjective well-being in collegiate baseball athletes. We hypothesize that there will be a negative relationship between baseball-specific training load and subjective well-being, indicating that as training load increases, subjective well-being decreases.

Methods

Participants were recruited from two collegiate baseball teams that participated in the fall season. Participants must have been between the ages of 18-25 and have

access to the training load and well-being surveys via a smartphone or computer.

Exclusion criteria included current pain or injury that limits participation, injury or pain

that limited activity within the last 3 months, no previous surgery within the last year,

and no self-reported mental health disorder, including but not limited to anxiety,

depression, or mood disorder. A longitudinal design was used for the current study.

Participants completed a playing and injury history form regarding their baseball

experience to ensure that they meet all inclusion and exclusion criteria. Participants

filled out daily well-being and training load surveys on a computer or smartphone

device. Training load was reduced into arm-specific and body-specific cumulative

session rating of perceived exertion (sRPE) and acute-to-chronic workload ratio

(ACWR). To qualify for the statistical analysis for this study, participants were required

to meet all inclusion and exclusion criteria and answer at least 50% of the training load

and well-being surveys from the previous 28 days, to correspond with the cumulative

load measures used in the current study. Once re-assessed with these a priori rules, the

final dataset contained 19 participants that combined for 112 total cases (age =

20.1±1.3 years, height=195.4± 6.3cm, mass=92.6 ± 11.8kg).

Subjective Well-being Assessment

Subjective well-being was assessed with the Daily Baseball Readiness Survey

(**Appendix 2**). This survey was developed to track daily subjective well-being that may

play a role in injury risk, sport performance, or training adaptations. The Daily Baseball

Readiness Survey was completed each morning prior to activity on a computer or

smartphone device (Qualtrics LLC, Provo, UT, USA). The survey consists of 8

questions and asked participants to rate their readiness to participate in sport, stress,

fatigue, and soreness on a Likert scale: readiness was rated from 0 to 100; fatigue, stress, and soreness was rated from -5 to +5. Scores closer to the minimum rating recorded on the survey were associated with negative subjective measures (low readiness, high stress, high soreness, and high fatigue), and scores closer to the maximum rating recorded on the survey were associated with positive subjective measures (high readiness, low stress, low soreness, and low fatigue). Participants also indicated where their soreness was located. The average of readiness, fatigue, stress, and soreness of the previous 7 days was used as a dependent variable in the statistical analyses.

Training Load Assessment

Baseball specific training load was assessed via the Daily Training Load Assessment Survey (**Appendix 3**). This survey was developed to feasibly and conveniently collect pertinent baseball-specific training variables through a computer and smartphone-based application (Qualtrics LLC, Provo, UT, USA). The Daily Training Load Assessment Survey was collected each day following activity. Participants reported the duration of their activity in minutes and the number of throws that they performed during baseball participation for the day. Duration, recorded in minutes, was defined as all aspects of baseball participation, strength training, and conditioning. A throw was defined as any throw outside of warm-ups, including long toss, flat ground, bullpens, live games, and fielding practice. Previous evidence indicates that throws between 18 meters and 55 meters demonstrate similar joint loads,[138] and throws of over 37 meters also demonstrate joint loads that are similar to baseball pitching.[19] Since these loads are very similar, all throws were equally weighted in this study.

Participants were asked to provide their rating of perceived exertion (RPE) experienced during baseball participation and any current training session, recorded on a scale from 0-10. The Daily Training Load Assessment Survey provided an image for participants to use as a reference to determine their level of exertion. Participants provided RPE with regards to two separate body regions: one regarding total body exertion and one regarding arm specific exertion. RPE was used in this study to quantify the perceived exertion during baseball related training and participation. Previous research has indicated that RPE demonstrates high reliability and validity when compared against heart rate methods of internal load[184,199] and training impulse.[184–187]

Training Load Data Reduction

Data from the Daily Training Load Assessment Survey was first reduced into daily total loads. Daily total body sRPE was calculated each day as the product of time and total body RPE. Daily arm-specific sRPE was calculated each day as the product of throw count and arm-specific RPE.

Four 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, the daily body-specific sRPE for the most recent 28 days was added together. To obtain the 4-week arm-specific cumulative sRPE, the daily arm-specific sRPE for the most recent 28 days were added together. The body-specific ACWR was calculated by taking the average daily body-specific sRPE of the most recent 7 days and dividing it by the average daily body-specific sRPE of the most recent 28 days. The arm-specific ACWR was calculated in a similar manner:

taking the average daily arm-specific sRPE of the most recent 7 days and dividing it by

the average daily arm-specific sRPE of the most recent 28 days. To better interpret the

results of the cumulative sRPE, the variables were rescaled. For body-specific

cumulative sRPE, all variables were divided by 28, and then again by 120, so the

outcome variable represented the average daily RPE of a two-hour training session

over the previous 28 days. The 4-week cumulative arm-specific sRPE variable was

divided by 25 and then again by 28, so this value would then represent the average

daily RPE of a 25-throw training period over the previous 28 days.

Statistical Analysis

Given compliance challenges of the daily collection, missing data existed within

the data. Data responsiveness was plotted by day to ensure that this data was

completely missing at random, and then missing data was handled through multiple

imputation techniques.[252–254] This method is preferred over other types of imputation,

such as single imputation, closest match, and standard likelihood methods.[253] Multiple

imputation replaces missing values with pseudo-random values based on observed

values within the dataset for a given individual while maintaining non-missing data

points within the dataset.[253] Subject ID, team, date, practice type, and playing position

were utilized to impute missing data via predictive mean matching for the daily well-

being and training load data. Once the data imputation process was completed and a

single data set was created, training load and well-being variables were calculated.

Variables were plotted with the training load variable on the x-axis and the dependent

variables on the y-axis prior to performing statistical analysis. Scatterplots were graphed

with a locally weighted scatter-plot smoothing line to determine if the relationship

between the training load and dependent variables was linear or non-linear. Previous research indicates that the relationship between training load and injury risk may be non-linear, with the risk of injury increasing exponentially as ACWR increases,[65] so non-linear relationships were probed to identify if a non-linear relationship exists between baseball specific training load and subjective well-being outcomes.

The relationship between subjective well-being outcomes and training load was assessed with a random intercepts linear mixed model. The model utilized subject, and team as random intercepts, to account for any inter-item variance associated with these measures. The average readiness, fatigue, stress and soreness from the previous 7 days served as the dependent variable. The independent variables were weeks from the beginning of the semester (time) and the training load variables (4-week cumulative body-specific sRPE, 4-week cumulative arm-specific sRPE, body-specific ACWR, and arm-specific ACWR). Arm-specific and body-specific training load outcomes were placed in separate models to prevent any influence on the outcome variable that would be due to multicollinearity between arm-specific and body-specific training load. Variance inflation factors and correlation coefficients were utilized to ensure that there was no multicollinearity between the ACWR and sRPE outcomes. Variables were considered significant predictors when the alpha level of 0.05 set a priori. Point estimates, standard errors, and 95% confidence intervals were calculated for each model.

Results

Descriptive Statistics

Baseball-specific training load and subjective well-being descriptive statistics are presented in **Table 1**. Overall, ACWR values indicated stable training states near 1.0, indicating the average acute loads and the average chronic loads were relatively even. Arm-specific and body-specific loads deviated slightly, with more variance present in the body-specific cumulative sRPE. Fatigue and stress demonstrated more positive values, indicating low fatigue and low stress, and the average soreness was near the middle of the scale values, which were 0-10.

Table 16. Descriptive Statistics for baseball specific training load and subjective well-being. Data is presented as mean ± standard deviation.

Baseball-Specific Training Load	Arm ACWR	1.023	±	0.530
	Arm Cumulative sRPE	3.032	±	1.580
	Body ACWR	1.004	±	0.537
	Body Cumulative sRPE	4.129	±	2.230
Subjective Well-Being	Readiness	78.146	±	13.107
	Fatigue	1.401	±	1.519
	Stress	1.643	±	1.634
	Soreness	4.534	±	1.076

Average Weekly Readiness

There was no apparent polynomial trend to the scatterplots, so linear models were utilized to assess the relationship between weekly average readiness and training

load measures. After accounting for subject and team with random intercepts, a significant negative linear relationship was present between weekly readiness and arm-specific cumulative sRPE (F=4.06, p=0.047). For body-specific training load variables, there was a significant negative linear relationship between weekly readiness and body-specific cumulative sRPE (F=5.91, p=0.017). These results indicated that increases in arm-specific cumulative sRPE and body-specific sRPE led to lower self-reported readiness. There was no significant influence of arm-specific (F=1.41, p=0.0238) or body-specific ACWR (F=2.544, p=0.114) on average weekly readiness. **Table 16** presents the model parameters between average weekly readiness and training load.

Table 17. Model parameters from the statistical analyses between average weekly readiness and training load.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	95% CI
Readiness	Linear	ID*	Intercept			90.825	8.061	(74.05, 107.80)
		Team*	Time	2.7845	0.0989	-0.676	0.406	(-1.48, 0.11)
			Arm ACWR	1.4087	0.2387	-2.270	1.913	(-6.01, 1.46)
			Arm Cumulative sRPE*	4.0631	0.0471	-1.854	0.920	(-3.65, 0.01)
Readiness	Linear	ID*	Intercept			94.211	8.956	(75.66, 113.10)
		Team*	Time	3.8362	0.0534	-0.845	0.432	(-1.68, 0.003)
			Body ACWR	2.5441	0.1145	-3.030	1.900	(-6.85, 0.68)
			Body Cumulative sRPE*	5.9133	0.0171	-1.630	0.670	(-2.89, -0.24)

Average Weekly Fatigue

      When visualized on a scatterplot, there was no apparent polynomial relationship. Therefore, linear models were utilized to assess the relationship between weekly average fatigue and training load measures. After accounting for subjects and team, there was no significant relationship between weekly fatigue and arm-specific training ACWR (F=0.018, p=0.892) or arm-specific cumulative sRPE (F=2.82, p=0.0961). Additionally, there was no influence of any body-specific training load variables on weekly average fatigue and body-specific ACWR (F=0.167, p=0.684) or body-specific cumulative sRPE (F=1.40, p=0.239). Neither arm-specific or body-specific training load seem to influence self-reported fatigue. **Table 18** presents model parameters between average weekly fatigue and training load.

Table 18. Model parameters from the statistical analyses between average weekly fatigue and training load.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	95% CI
Fatigue	Linear	ID*	Intercept			2.663	0.725	(1.27, 4.10)
		Team	Time	3.4954	0.0652	-0.080	0.043	(-0.16, 0.00)
			Arm ACWR	0.0184	0.8926	-0.027	0.200	(-0.41, 0.36)
			Arm Cumulative sRPE	2.8260	0.0961	-0.174	0.104	(-0.37, 0.04)
Fatigue	Linear	ID*	Intercept			2.583	0.781	(1.12, 4.10)
		Team	Time	3.2116	0.0769	-0.083	0.046	(-0.17, 0.00)
			Body ACWR	0.1667	0.6842	-0.082	0.202	(-0.47, 0.31)
			Body Cumulative sRPE	1.4011	0.2396	-0.090	0.076	(-0.23, 0.07)

Average Weekly Stress

There was no apparent polynomial relationship, so linear models were used to assess the relationship between weekly average stress and training load. When accounting for subjects' random effects, there was a significant linear association between weekly average stress and arm-specific ACWR (F=5.03, p=0.027) and arm-specific cumulative sRPE (F=16.07, p<0.001). After accounting for subject as a random effect, there was a significant relationship between weekly average stress and body-specific ACWR (F=6.92, p=0.010). There was a significant effect of time in both the arm-specific (F=12.06, p<0.001) and body-specific model (F=6.92, p=0.010). These results indicated that higher arm-specific and body specific training loads led to more negative responses of self-reported stress. **Table 19** presents the model parameters between average weekly stress and training load.

Table 19. Model parameters from the statistical analyses between average weekly stress and training load.

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	95% CI	
Stress	Linear	ID*	Intercept			4.690	0.635	(3.44,	5.95)
			Time*	12.0643	0.0008	-0.144	0.042	(-0.22,	-0.06)
			Arm ACWR*	5.0326	0.0277	-0.440	0.196	(-0.81,	0.05)
			Arm Cumulative sRPE*	16.0725	0.0001	-0.416	0.104	(-0.62,	-0.20)
Stress	Linear	ID*	Intercept			3.760	0.688	(2.42,	5.09)
			Time*	6.9298	0.0101	-0.126	0.048	(-0.21,	-0.03)
			Body ACWR*	7.5185	0.0076	-0.571	0.208	(-0.97,	-0.16)
			Body Cumulative sRPE	1.3968	0.2403	-0.092	0.078	(-0.24,	0.06)

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Average Weekly Soreness Intensity

      Since there was a curvilinear nature to both arm and body-specific ACWR lines of best fit, quadratic models were probed. After accounting subjects and team as a random effect, there was a significant linear relationship between arm-specific ACWR and average weekly soreness intensity (F=6.68, p=0.011). There was also a significant linear relationship between body-specific ACWR and soreness intensity (F=22.57, p<0.001). There was also a significant quadratic relationship between weekly average soreness and body-specific ACWR (F=19.27, p<0.001). There was no statistically significant effect of time on weekly average soreness intensity. The results indicate that as arm-specific ACWR increases, soreness intensity decreases overall. The quadratic relationship indicates that soreness intensity will be reported at its highest with the body-specific ACWR is either very high or very low, and the soreness intensity will be reported at its lowest when the body-specific ACWR is moderate. **Table 20** presents model parameters and statistics from the analyses between average weekly soreness intensity and training load.

Table 20. Model parameters from the statistical analyses between average soreness intensity and training load

DV	Type	Random Effect	Fixed Effects	F value	P-value	Estimate	Std. Error	95% CI
Soreness	Linear	ID*	Intercept			5.113	0.532	(4.10, 6.11)
		Team	Time	0.7398	0.3922	0.031	0.036	(-0.03, 0.10)
			Arm ACWR*	6.6656	0.0116	-0.443	0.172	(-0.77, -0.11)
			Arm Cumulative sRPE	1.3966	0.2406	-0.098	0.083	(-0.28, 0.06)
Soreness	Linear	ID*	Intercept			4.925	0.568	(3.85, 5.96)
		Team	Time	2.6334	0.1084	0.059	0.036	(-0.01, 0.12)
			Body ACWR*	22.5763	0.0000	-0.754	0.159	(-1.06, -0.44)
			Body Cumulative sRPE	0.0419	0.8382	-0.012	0.058	(-0.13, 0.09)
Soreness	Quadratic	ID*	Intercept			4.122	0.418	(3.31, 4.91)
		Team	Time	2.8709	0.0940	0.058	0.034	(-0.01, 0.12)
			Body ACWR*	19.2785	<0.0001	2.810	0.765	(1.38, 4.34)
			Body Cumulative sRPE	0.0208	0.9794	0.024	0.839	(-1.59, 1.63)

Discussion

The results of the study indicated that baseball specific load influences subjective well-being. Both arm-specific and body-specific ACWR and cumulative sRPE indicate a relationship to average weekly stress, readiness, and soreness intensity. Additionally, there is a significant influence of time, measured as weeks from the beginning of the fall semester, on the subjective well-being outcomes. College athletes' readiness and stress should be monitored, especially during high periods of intensive training. The combination of stress from school as well as stress from athletics participation could overload an athlete and force them into a non-functional overreaching state. As previously mentioned, subjective well-being and training load has been linked to injury in athletic populations. Monitoring both may provide a more comprehensive assessment of potential injury state in baseball athletes.

Previous research has indicated that pitch counts and throw counts are related to injury in baseball athletes,[56,60,75,175] but evidence exists that standard pitch counts are not great measures of load, as they only represent 57.8% of throws made on a given day.[195] This suggests pitch counts might be rudimentary measures of load, and recent research demonstrates more robust measures of participation that utilize internal and external load measures are related to injury risk.[65,74,202] In cricket athletes, there is a significant association between load and injury risk when using both the count of overs (a standard throw in cricket) and an internal load measure of RPE.[190] The sport demands of cricket are similar to those of baseball, so these measures of sport participation, via sRPE, may be useful to quantify baseball participation. The evidence from this study indicates that the sRPE based measures are linked to subjective well-

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being, similar to previous studies.[264] The addition of an internal load measure may be a very beneficial to understanding how baseball participation influences an athlete from a perceptual or a physiological perspective. While external load may indicate the work performed, the perception and physiological response may indicate an athlete's overall response to activity. Baseball players with high fitness may react differently to a specific external load that those with low fitness. Additionally, consecutive baseball participations of similar external loads, for instance playing on back to back days, may lead to different perceptual ratings of difficulty or physiologic response to that activity. Future research should continue to incorporate internal load measures, either through perceptual or physiologic measures, to assess both the physical work and the perception or physiological response, as this might lead to a more robust quantification of baseball participation.

Baseball is a unique sport and likely requires a unique quantification of participation. While other sports often utilize a standard sRPE, utilizing a duration of activity and a standard RPE, these measures are not the only type of load that a baseball player experience. Baseball's unique sport requirements of throwing may require different questions to be asked to collect more specific measures of baseball participation. In this study, we parsed out arm specific and total body specific training load, utilizing both throws and duration of activity as external loads and then a related RPE to the corresponding body region. To identify if cumulative load or large changes in load are related to injury, this study also incorporated ACWR and cumulative 28-day sums. Both the arm-specific and body-specific training load variables are linked to average weekly well-being variables. This incorporation of both arm-specific and body-

specific load may be critical to assisting those at risk for injury, but that relationship is beyond the scope of this study. There is a previous link in training load and injury[65,73] as well as a link between subjective well-being and injury.[192,202] The current results indicate the link between training load and well-being, so future studies should utilize the sRPE measures to better ascertain the link between baseball specific training load and injury risk.

Subjective well-being has previously been linked to injury in athletes,[192,202,211] and negative changes in well-being are readily present in athletes that are overreaching in their training.[208,237,255] While previous evidence either intentionally modifies training to overreach,[237] or monitors performance variables to identify when overreaching is present,[255] it can be hypothesized that the ACWR can indicate when athletes are overreaching. Athletes that demonstrate significantly higher levels of acute load compared to their chronic load may be overreaching in their training, as evidence indicates that high ACWR values are associated with injury rate.[65,73] Additionally, overall chronic training may also be an indicator of overreaching, as chronic loads are associated with injury in baseball[54,55,75] and other field sports.[74,202] The current study utilized both chronic loads and ACWR, and demonstrated that arm-specific and body-specific ACWR demonstrated significant associations of subjective ratings of readiness, stress, and soreness, and cumulative sRPE was associated with stress and readiness. With the previous link between subjective measures of well-being and injury, and the link between training load and injury, this study demonstrates the link between the two variables as well. These measures may be useful together to identify potential injury risk of baseball athletes, although this study did not investigate the link between subjective

well-being and injury risk. Assessments of subjective well-being and training load may be used in tandem to indicate the overall well-being of baseball athletes. When high training loads are present, the subjective well-being assessments may be able to corroborate whether a baseball athlete is in an overreaching state. Future research should assess multivariate influence of both training load and subjective well-being on injury risk in baseball athletes.

Previous evidence in baseball athletes indicates that self-reported fatigue is a major risk factor of injury.[54,59,60] Baseball athletes that play consistently despite arm fatigue are up to 36 times more likely to become injured that those who play without arm fatigue.[54] It is interesting to note that there was no significant relationship between the self-reported fatigue and the baseball specific training load in this study. Rather, stress, readiness, and soreness intensity were more related to arm-specific and body-specific loads from baseball participation. Previous studies asked baseball athletes retrospectively to indicate if arm fatigue was present during their throwing bouts,[54] but the current study asked for well-being measures on a daily basis, prior to activity for the day. This may lead to more reliable assessments, as recall bias is limited and the well-being is collected in real-time. Fatigue is also a multi-dimensional construct that is often poorly defined and collected. As such, stress, soreness intensity, and readiness may be better assessments of well-being, and should be investigated to identify if they are related to injury risk in baseball athletes.

College athletes are asked to perform a considerable amount of work external to their sport, as indicated by the most recent NCAA Goals study. College athletes are expected to participate in sport for up to 34 hours per week in season while still

dedicating up to 38.5 hours per week on academics.[265] Evidence suggests that college students are significantly stressed, with up to 72.9% of students indicating they suffer from psychological distress and 86.3% indicating high anxiety scores on the Perceived Stress Scale.[266] The current study indicated a significant negative relationship between time, measured as the weeks from the first week of school, and subjective ratings of stress. As an athlete moves through the semester, there may be more educational expectations, including exams, midterms, projects, and finals. Hypothetically, it can be reasoned that each of these carries a level of stress with it that might accumulate throughout the season, with finals week being a significant stressor. While the results from this study are very raw in terms of temporal parameters, the link suggests that more research should be performed to assess the potential influence of school requirements on athlete's well-being and potential injury risk.

This study is not without limitations. Athletes were asked to take the well-being survey every day prior to activity and take the training load survey after activity, but there was no control to ensure that the temporal parameters were met. Delaying the training load assessment may lead to a change in perception of the overall practice. Previous research papers have utilized paper and pencil collections of RPE to ensure that this data is collected in a timely manner. The use of a mobile device to collect these limits influence between teammates, but there is also no way to control the exact timeframe for collection. Future research should identify the benefits and drawbacks of different collection methods of RPE. Additionally, the missing data in this study was aimed to be imputed via well accepted imputation methods, but the inclusion of this data may skew the results slightly as well. Future research that investigates different

collection methods should also highlight the responsiveness of the surveys. This study was performed on elite male college baseball players, so the generalizability may be limited and not as applicable to other populations.

Conclusions

Baseball training load influences subjective well-being, as both arm-specific and body-specific training load variables demonstrate significant associations with average weekly readiness, stress, and soreness intensity. Athletes, coaches, and clinicians should utilize this data to create evidence programs that appropriately prescribe baseball specific loads to reduce negative responses in subjective well-being. The use of both subjective well-being data and training load data may provide a more robust assessment of injury risk, as both subjective well-being and training load has previously been linked to injury risk. When athletes present with high training load, utilizing the well-being measures to corroborate negative effects of training may give clinicians more evidence to alter the current training schedule to prevent the negative effects of overreaching. Future research should investigate the multivariate influence of baseball-specific training load and subjective well-being on injury risk in baseball athletes.

APPENDICES

These appendices are not to be copyrighted.

Appendix 1. Demographics and Injury History

ID:								

Introduction: Please provide us with some demographic information regarding height, weight, age, race and ethnicity.

Please put the most recent measurement of height, weight, and age in the appropriate spaces below:

Age:_____

Height:_____   Weight:_____

Please place an X in the category that most fits your race and ethnicity.

Racial Category	**Ethnic Category**	
	Not Hispanic Or Latino	Hispanic or Latino
Native American/Alaska Native		
Asian		
Native Hawaiian or Other Pacific Islander		
Black or African American		
White		
More than one Race		
Unknown		

Tell Us About Your Baseball Participation Experience and Arm Injuries

Part 1: Tell us about your Baseball Participation Experience

1. What position(s) do you expect to play for your Baseball team this season?

☐ Pitcher   ☐ 3rd base

☐ Catcher   ☐ Short stop

☐ 1st base   ☐ Outfield

☐ 2nd base   ☐ Unknown/Not sure

1a. Of the positions checked above, which is your PRIMARY position?

☐ Pitcher   ☐ 3rd base

☐ Catcher   ☐ Short stop

☐ 1st base   ☐ Outfield

☐ 2nd base   ☐ Unknown/Not sure

1b. Of the positions checked above, which is your SECONDARY position?)

☐ Pitcher   ☐ 3rd base

☐ Catcher   ☐ Short stop

☐ 1st base   ☐ Outfield

☐ 2nd base   ☐ Unknown/Not sure

2. Including the Spring 2017 season, how many years have you played baseball,

<u>INCLUDING</u> t-ball?

☐	<1 year	☐	5 years	☐	10 years	☐	15 years
☐	1 year	☐	6 years	☐	11 years	☐	16 years
☐	2 years	☐	7 years	☐	12 years	☐	17 years
☐	3 years	☐	8 years	☐	13 years		
☐	4 years	☐	9 years	☐	14 years		

3. Including the Spring 2017 season, how many years have you played baseball,

<u>EXCLUDING</u> t-ball?

☐	<1 year	☐	5 years	☐	10 years	☐	15 years
☐	1 year	☐	6 years	☐	11 years	☐	16 years
☐	2 years	☐	7 years	☐	12 years	☐	17 years
☐	3 years	☐	8 years	☐	13 years		
☐	4 years	☐	9 years	☐	14 years		

4. Within the past year, please check all the seasons you played baseball on an

organized team (ex. Club team, summer ball, fall ball, travel ball)?

2018	☐ Spring	☐ Summer	☐ Fall	☐ Did not play baseball

5. Within the past years, please check all seasons you <u>PLAYED</u> baseball on <u>multiple organized teams at the same time</u>?

2018	☐ Spring	☐ Summer	☐ Fall	☐ Did not play baseball in

6. Please check all the organized team/individual sports you participated in the past year. (This does not include sports you played in as a part of your class activities or in pickup games)

☐ None   ☐ Tennis

☐ Football   ☐ Swimming

☐ Basketball   ☐ Cross Country

☐ Soccer   ☐ Track

☐ Lacrosse   ☐ Volleyball

☐ Wrestling   ☐ Waterpolo

☐ Golf   ☐ Others (Please spec ☐☐☐☐☐☐☐☐☐☐☐☐

Part 2: Tell us about your Pitching Experience

If you have NEVER been a pitcher, please skip this page and continue with the

1. Including the 2016 season, how many years have you pitched on an organized

team?
☐ <1 year ☐ 5 years ☐ 10 years

☐ 1 year ☐ 6 years ☐ 11 years

☐ 2 years ☐ 7 years ☐ 12 years

☐ 3 years ☐ 8 years

☐ 4 years ☐ 9 years

2. Within the past year, please check all the seasons that you pitched in an

organized team. If you pitched, please check the role you played as a pitcher

during each season (ex. starter vs bull pen/relief pitcher).

Summer 2018 ☐ Did not Pitch ☐ Pitched ⟶ ☐ Starter ☐ Relief ☐ Equal

Spring 2018 ☐ Did not Pitch ☐ Pitched ⟶ ☐ Starter ☐ Relief ☐ Equal

Fall 2017 ☐ Did not Pitch ☐ Pitched ⟶ ☐ Starter ☐ Relief ☐ Equal

3. Please check the types of pitch you throw in games

☐ Fastball ☐ Knuckle-curve ball

☐ Curveball ☐ Change-up

☐ Slider ☐ Slurve

☐ Knuckle ball ☐ Other (Please specif ☐☐☐☐☐☐☐☐☐

Part 3: Elbow Injuries and Pain During Your Baseball Career

Have you ever had an ELBOW throwing-related injury that was sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your baseball career?

☐ No (if no, proceed to next page)   ☐ Yes

> If YES, please **check ALL** the injuries you had that were <u>sufficiently bad that it stopped</u>
>
> <u>you from participating in practice or games for at least 7 days during your baseball</u>

		When did you have the injury for the first time?	Did you see a doctor for this?	Did you get surgery
☐	Ulnar collateral ligament injury (Sprain, tear, rupture, irritation)	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐	Tendonitis on the inside of the Elbow ("Medial epicondylitis")	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐	Other Tendonitis (i.e. Biceps, Triceps, lateral epicondylitis)	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐	Stress fracture or bone chip	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐	Ulnar nerve injury	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐	Growth plate fracture	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐	Non-specific pain/ soreness From overuse	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐	Other: Please specify	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	No ☐ Yes ☐

↓

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Part 4: Shoulder Injuries and Pain During Your Baseball Career

Have you ever had a SHOULDER throwing-related injury that was sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your baseball career?

☐ No (If no, proceed to the next page) ☐ Yes

If YES, please **check ALL** the injuries you had that were <u>sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your baseball career</u>, and answer the questions to the right.

	When did you have the injury for the first time?	Did you see a doctor for this?	Did you get surgery?
☐ Rotator cuff (tendonitis, strain Irritation, tear, impingement)	(Month) (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐ Labrum injury (tear, irritation SLAP lesion)	(Month) (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐ Biceps tendon (tendonitis, Subluxation, irritation)	(Month) (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐ Other muscle strain (not rotator or biceps)	(Month) (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐ Bursitis	(Month) (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐ Stress fracture or bone chip	(Month) (Year	☐ No ☐ Yes	No ☐ Yes ☐
☐ Growth plate fracture	(Month) (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐ Thoracic outlet syndrome	(Month) (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐ Non-specific pain/ soreness From overuse	(Month) (Year)	☐ No ☐ Yes	No ☐ Yes ☐
☐ Other: Please specify	(Month) (Year)	☐ No ☐ Yes	No ☐ Yes ☐

↓

☐☐☐☐☐☐☐☐☐☐☐☐☐☐

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Daily Baseball Readiness Survey

Start of Block: Name

1. Enter your Name

_____

End of Block: Name

Start of Block: General Readiness

2. How would you rate your **READINESS** to train today, with 100 being normal?

	Not ready	Moderately ready	Fully ready
	0 10 20 30 40 50 60 70 80 90 100		
Readiness (1)			
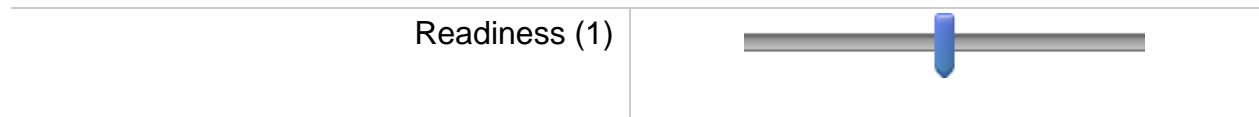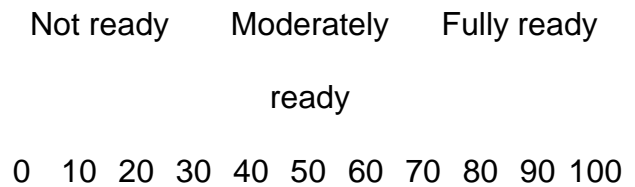
End of Block: General Readiness

Start of Block: Specifics

3. How well did you **SLEEP** last night?

	Not well	Moderately well	Very well
	-5 -4 -3 -2 -1 0 1 2 3 4 5		
Sleep Quality (1)			
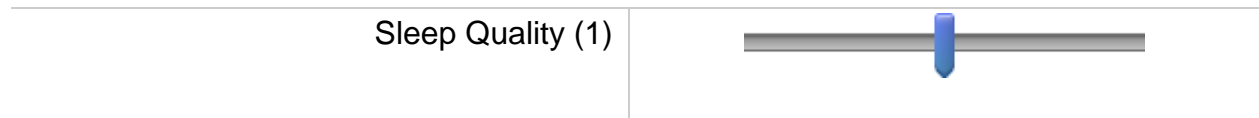
4. How **FATIGUED** do you feel?

	Very Tired	Somewhat Tired	Not Tired at All

-5 -4 -3 -2 -1 0 1 2 3 4 5

Fatigue Level (1)	
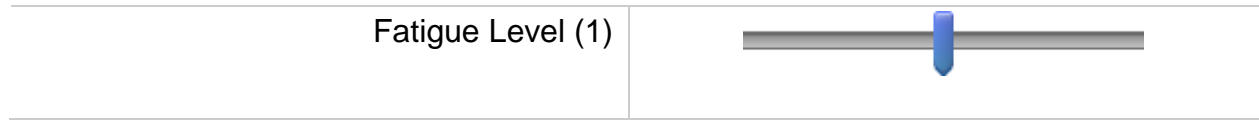
5. How would you rate your **STRESS** level today?

	Very Stressed	Moderately Stressed	Not Stressed

-5 -4 -3 -2 -1 0 1 2 3 4 5

Stress Level (1)	
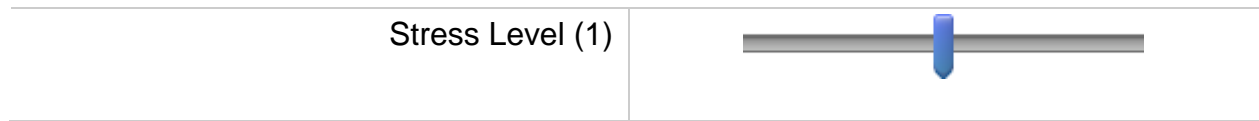
6. How would you describe your **MOOD** today?

1 (1)

2 (2)

3 (3)

4 (4)

5 (5)

X→
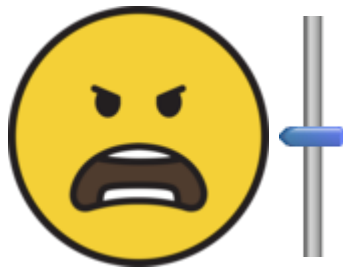
7. Are you **SORE** today?

○ Yes (1)

○ No (0)

Display This Question:
If Are you SORE today? = Yes

8. Select the locations that are **MOST** sore.

	Right Side (1)	Left Side (2)
Head (4)	☐	☐
Chest (5)	☐	☐
Shoulder (6)	☐	☐
Elbow/Forearm (20)	☐	☐
Abdominals (7)	☐	☐
Hip Flexor (8)	☐	☐
Groin (9)	☐	☐
Quads (10)	☐	☐

Knee (11)

☐   ☐

Shin (12)

☐   ☐

Foot (13)

☐   ☐

Neck (14)

☐   ☐

Upper Back (15)

☐   ☐

Lower Back (16)

☐   ☐

Gluteals (17)

☐   ☐

Hamstrings (18)

☐   ☐

Calves (19)

□ □

Wrist/Hand (21)

□ □

---

9. How **SORE** are your today?

	Very Sore	Moderately sore	Not Sore
	-5 -4 -3 -2 -1 0 1 2 3 4 5		
Soreness Level (1)	▬▬▬▬▬|▬▬▬▬		

End of Block: Specifics

Daily Training Load Assessment Survey

Start of Block: Default Question Block

1. Enter your name.

_____

2. How many minutes did you play baseball today?

_____

3. About how many throws did you make today?

_____

4. About how many swings did you take today?

_____

How was training today?

Rating	Descriptor
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal

---

5. Refer to the image above.

On a scale of 0-10, how was your baseball participation today?

Rest   Maximal

0   1   2   3   4   5   6   7   8   9   10

Total Body Rating (1)	

How was training today?

Rating	Descriptor
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal

6. Refer to the image above.

Only thinking about your throwing arm, how was your baseball participation today?

Rest   Maximal

0 1 2 3 4 5 6 7 8 9 10

Arm Rating (1)

7. Did you do any arm care today?

This includes bands, arm weights, shoulder stretching, weighted baseballs, or other exercises designed to prevent injury in your throwing arm.

○ Yes (1)

○ No (2)

---

8. Did you lift weights today?

○ Yes (1)

○ No (2)

End of Block: Default Question Block

Appendix 4: Physical Variables over Time

Limb	Time	TROM			ERPF			IRPF		
DOM	W00	177.902	±	10.265	119.621	±	28.627	199.636	±	47.610
	W04	176.667	±	10.614	111.084	±	27.655	199.856	±	45.361
	W08	175.805	±	9.876	119.178	±	30.440	198.864	±	49.283
	W12	178.291	±	10.861	124.862	±	26.984	197.492	±	44.449
	W16	172.238	±	15.345	114.773	±	27.258	176.166	±	35.719
ND	W00	181.691	±	11.478	127.826	±	32.005	190.469	±	51.016
	W04	186.333	±	10.427	123.458	±	31.315	192.002	±	40.752
	W08	180.570	±	11.047	124.895	±	28.809	178.919	±	41.897
	W12	197.306	±	125.877	125.490	±	26.116	185.080	±	40.976
	W16	176.645	±	13.140	116.816	±	29.600	160.529	±	34.854

Strength and Range of Motion over time. Means ± Standard deviations.

Limb	Time	Grip strength		OHRT		BBRT	
DOM	W00	203.181 ±	36.219	11.063 ±	2.461	21.829 ±	5.969
	W04	199.042 ±	40.130	10.934 ±	2.025	21.242 ±	5.000
	W08	184.199 ±	38.504	10.983 ±	2.614	21.350 ±	5.231
	W12	201.935 ±	35.012	10.453 ±	2.781	22.359 ±	5.640
	W16	205.362 ±	35.538	9.738 ±	2.881	21.440 ±	5.061
ND	W00	194.392 ±	35.630	12.113 ±	2.553	15.090 ±	5.135
	W04	187.297 ±	35.393	12.384 ±	2.089	14.182 ±	4.444
	W08	175.304 ±	38.371	12.650 ±	2.465	15.090 ±	4.921
	W12	187.176 ±	32.124	11.805 ±	2.675	16.318 ±	5.131
	W16	188.975 ±	27.739	11.103 ±	2.674	15.984 ±	4.754

Grip Strength and reach test over time. Means ± Standard deviations

Limb	Time	SLBT			Jump Height			Jump Power		
Dom	W00	5.297	±	7.051	41.135	±	4.215	4455.303	±	443.754
	W04	12.412	±	7.033	35.431	±	7.906	4227.767	±	803.247

	W08	14.492	±	7.113	41.605	±	4.498	4497.164	±	407.249
	W12	13.266	±	9.354	38.988	±	6.341	4597.160	±	604.884
	W16	14.500	±	6.808	39.785	±	7.281	4480.165	±	280.578
ND	*W00*	5.108	±	6.744						
	W04	10.912	±	5.379						
	W08	12.932	±	6.099						
	W12	12.266	±	8.050						
	W16	13.619	±	7.109						

SLBT and CMJ over time. Means ± Standard deviations

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