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Patterns Of Participation And Performance In Youth Baseball Players

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PATTERNS OF PARTICIPATION AND PERFORMANCE IN YOUTH BASEBALL PLAYERS

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For Jeff.

“Baseball was, is and always will be to me the best game in the world.”

- Babe Ruth

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ABSTRACT

Baseball is a popular sport to play in the United States, with approximately 13-17 million athletes participating across all levels of competition. Youth (9-12 years) and adolescent (13-18 years) players comprise the majority of this population playing at the club and high school levels, yet less than 10% of research studies include athletes <18 years old. Despite increased awareness of the risks surrounding sports participation, youth and adolescent baseball players continue to report overuse injuries at alarming rates.

The lack of high-quality research describing athletic performance and injury risk factors, such as sport specialization, in young athlete populations poses a significant knowledge gap in the literature. The current investigation sought to establish the incidence of upper extremity (UE) injuries while examining population-specific risk factors in a cohort of youth baseball players (**Aim 1**). The current study also examined the measurement properties of normalized isometric shoulder strength, by 5 separate methods, for use as a multi-faceted clinical assessment tool that was responsive to changes in physical growth and development over time (**Aim 2**).

Youth baseball players were examined for baseline participation and isometric shoulder strength data and then prospectively followed via coach and parent surveys. Athletic exposures (AE) and the presence of UE injuries were tracked for each player. Chi square analyses were used to compare the frequency of UE injuries based on position group, sports specialization status and participation in additional specialty training. Odds

ratios as well as absolute and absolute risk differences with 95% confidence intervals (CI) were calculated between groups for **Aim 1**. A subset of athletes (n = 58) was physically re-examined during the follow-up period to establish the test-retest reliability of each of the normalized isometric shoulder strength measures. Repeated measures analyses of variance (ANOVA) were conducted to compare changes in isometric shoulder strength at 2 time points after normalizing to 5 separate measures of body size. Linear regression models were used to examine the relationships between normalized isometric shoulder torque measures and ball velocity in youth baseball players for **Aim 2**.

Results showed that youth baseball players demonstrated an UE injury incidence rate of 16.3/1000 AEs. Specialized athletes, who comprised 83.0% of this cohort, demonstrated a 15.9% increase in absolute risk for developing an UE injury when compared to multi-sport counterparts. Following comparisons across 5 methods of normalization, only torque, defined as the measure of shoulder strength divided by the corresponding ulnar length, demonstrated excellent reliability and detected significant changes between shoulder strength in each of the 4 measures tested. Torque was the most stable and reliable normalization method evaluated in this study. Modest but significant correlations were observed between shoulder scaption torque, shoulder external rotation (ER) torque at 0°and ball velocity suggesting that these measures were the most useful predictors of throwing performance in 9-12 year old baseball players.

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LIST OF ABBREVIATIONS

AE ....Athletic Exposure

ANOVA ....Analysis of Variance

AR ....Absolute Risk

ARD ....Absolute Risk Difference

BMI .... Body Mass Index

CI...Confidence Interval

Cm ....Centimeter

D..Dominant

ER .... External Rotation

HHD...Hand-Held Dynamometry

HT ....Humeral Torsion

ICC..Intraclass Correlation Coefficient

IR.. Internal Rotation

IRB ....Institutional Review Board

Kg.. Kilogram

LE...Lower Extremity

MDC .... Minimally Detectable Change

MHz .... Megahertz

MPH ....Miles Per Hour

ND.. Non-Dominant

Nm.. Newton Meter

NSAID .... Non-Steroidal Anti-Inflammatory Drug

OCEBM .... Oxford Centre for Evidence-based Medicine

OR .... Odds Ratio

PRISMA.....................Preferred Reporting Items for Systematic Review & Meta-Analysis

PT .... Physical Therapy

ROM .... Range of Motion

RR .... Rate Ratio

SD .... Standard Deviation

SEM .... Standard Error of Measure

SORT .... Strength-of-Recommendation Taxonomy

UE .... Upper Extremity

Wks .... Weeks

CHAPTER 1

INTRODUCTION

1.1 Upper Extremity Injuries in Youth Baseball Players

Baseball is a popular sport to play in the United States, with approximately 13-17 million athletes participating across all levels of competition.[31,51,143] Youth (9-12 years) and adolescent (13-18 years) players comprise the majority of this population playing nearly year-round with minimal rest at the club and high school levels.[4,31,51,143] Despite increased awareness surrounding the risks associated with overtraining, youth and adolescent baseball players continue to report overuse injuries at alarming rates.[12,19,90,91,136,140,148,154,155] The incidence of baseball-related overuse injuries in adolescent players was reported to be 1.3 – 4.0 injuries per 1,000 athletic exposures however this data is unknown in youth players.[31,137] The research does indicate that the majority of baseball-related overuse injuries are reported in the upper extremity (UE), specifically at the shoulder and elbow, however little is known about the etiology and development of these injuries in youth athletes.[6,31,137]

Despite evidence suggesting that sport specialization may be related to the development of overuse injuries in youth and adolescent athletes, its prevalence continues to increase in the U.S.[72,107] Research studies have previously defined sport specialization using a battery of criteria including year-round training in a single sport (>8 months/year), identification of a primary sport over additional sports and the cessation of additional sports to focus on a primary sport.[8,71,72,84] Established definitions exist in the literature, however less is understood about the public perception of sports specialization with parents and coaches.[71,72,84,107,108] The effects of sport specialization on UE injury risk has not been previously examined in the baseball literature. Other risk factors, such as excessive pitch counts, varied pitch types and faulty throwing mechanics, have been linked to the development of shoulder and elbow pain in youth throwers using self-report and survey data.[12,71,72,90,91,116,162] The USA Baseball Medical & Safety Advisory Committee has used this research to establish age-appropriate guidelines for pitch counts, pitch types and throwing mechanics.[12,19,90,91,136,140,148,154,155] The effectiveness of these recommendations on the reduction of baseball-related overuse injuries is unknown, as the extent of the problem has not been previously established in the literature. The absence of epidemiologic studies describing overuse injury rates in youth athletes combined with the lack of population-specific risk factor data pose significant knowledge gaps in the evaluation and treatment of this population. To address these gaps in the literature, the first aim of the current project was:

Aim 1: Examine the effects of population-specific risk factors on UE injury risk in a cohort of 9-12 year old male baseball players.

1. The primary objective of this study was to determine the specific incidence of baseball-related UE injuries using athletic exposures (number of team-recorded practices and games) as the denominator.
2. The secondary objective of this study was to examine the effects of player position, sport specialization and participation in specialty training on baseball-related UE injury risk.

1.2 Normalization Methods for Isometric Shoulder Strength in Youth Baseball Players

Upper extremity muscle strength is an important component in the assessment of throwing performance and injury prevention in baseball players.[17,28,44,50,52,61,97,105,148,156,160] Strength is defined as the amount of force a muscle can maximally produce during a single repetition.[67,68,70] Clinicians and researchers routinely use batteries of strength measures in performance assessments, injury diagnostics and return to sport decisions following injury.[17,33,61,148]

A variety of methods, including isokinetic, isometric and functional testing, have been used to assess upper extremity strength in athletic populations.[17,28,44,61,97,148,160] While isokinetic testing is considered the gold standard in strength assessment; the high equipment costs and lack of portability make it impractical for use outside of laboratory settings.[33,52,142] Isometric testing using hand held dynamometry (HHD) has proven to be a reliable, low cost and portable alternative to isokinetics in assessing strength, particularly in the throwing shoulder.[17,33,142,148]

While the majority of upper extremity strength testing has been conducted at the collegiate and professional levels, few studies have sought to assess strength measures in younger athletes.[17,44,61,97,105,148] One potential reason for this gap in the literature may be related to the inherent variability of strength measures, especially when assessed in physically developing populations.[67,68,70] Studies have shown that anthropometric measures, such as height and weight, influence the body's ability to produce force, suggesting that changes during growth and development may impact a youth athlete's muscle strength and performance measures.[44,67,68,97,105] Relying solely on the measure to quantify changes over time, without accounting for alterations in body size, may not adequately reflect how athletic performance and injury risk develop in youth populations.[67,68,70] Normalization is one option for assessing strength changes in physically developing populations however these methods have been inconsistently reported in the literature.[68,70]

Evaluating isometric shoulder strength in youth athletes is inherently different from collegiate and professional athletes.[67,68,92] Height, weight and neuromuscular control can fluctuate frequently in physically developing populations with the potential to rapidly change over short periods of time. Performance assessments that rely on absolute measures, without anthropometric normalization, may lack the ability to discern changes in muscle strength from changes in body size in youth populations.[67,68,70] Prior research studies suggest that normalization methods, which include body mass, body mass index (BMI), height, torque and percent of non-dominant shoulder strength described by Trakis[148] may be potential ways to assess muscle strength and changes in muscle strength over time in this population.[63,67,68] Accounting for these alterations in growth and development through normalization is critical to accurately assessing muscle function, throwing performance and injury risk in youth athletes.[67,68,92] Establishing an objective and reliable method for evaluating strength is an important step in understanding shoulder function in youth baseball players.[33,148] Once a reliable method has been established, the next steps are to examine the relationships between shoulder strength and ball velocity, a performance variable of interest in this population, and shoulder strength and UE injury risk in youth players. To address the lack of population-specific strength measures with related data in the youth athlete literature, the second aim of the current project was:

Aim 2: Compare the measurement properties of normalized isometric shoulder strength, using 5 separate methods, for use as a multi-faceted clinical assessment tool that was responsive to changes in physical growth and development over time in a cohort of 9-12 year old male baseball players.

1. The primary objective of this aim was to assess the test-retest reliability of 4 isometric shoulder strength measures.
2. The secondary objective of this aim was to assess changes in normalized isometric shoulder strength over time using baseline and follow-up evaluation measures.
3. The tertiary objective of this aim was to examine the relationship between normalized isometric shoulder strength measures and ball velocity, a performance variable of interest in youth baseball players.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Abstract

Introduction: Despite rising awareness of the risks associated with sports participation, overuse injuries continue to increase in youth athlete populations. Physeal injuries are one type of overuse injury exclusive to pediatric populations that are often sustained during athletic practice or competition. Overuse physeal injuries are, in theory, preventable, however little consensus has been reached surrounding the risk factors, prevention and treatment strategies reported in the literature.

Objective: The purpose of this systematic review was to summarize the best available evidence concerning overuse physeal injuries in youth and adolescent athletes. The information can then be used to guide the development of prevention and treatment programs specific to this population as well as identify any knowledge gaps for future research.

Methods: PubMed and Academic Search Complete (EBSCOhost) were explored using *physeal injuries* from January 1950 through May 2015. Original research studies performed in athletic populations with mechanisms of injury related to sport were chosen. A total of 24 studies were included in this systematic review.[1]

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[1]Arnold A, Thigpen CA, Beattie PF, Kissenberth MJ, Shanley E. Overuse Physeal Injuries in Youth Athletes. *Sports Health.* 2017;9(2):139-147. Reprinted here with permission of publisher.

Results: Risk factors for injury include periods of accelerated growth, chronological age, body size, training volume and history of previous injury. Injury prevention strategies currently emphasize participation limitations and sport-specific training programs in skeletally immature athletes. The most effective treatment following an overuse physeal injury was an extended period of active rest and joint immobilization when necessary.

Overall Strength-of-Recommendations Taxonomy (SORT): C.

Conclusion: Overuse physeal injuries are multi-factorial in nature. Muscular imbalances following accelerated growth periods are thought to predispose young athletes to overuse injuries. Modifiable risk factors such as flexibility, strength and training volume should be regularly monitored in an effort to prevent these injuries when possible.

Keywords: physis; physeal injury; overuse; sports injuries; pediatric injuries

2.2 Introduction

An estimated 30 million children in the U.S. are involved annually in organized sport.[1,20] Despite rising awareness of the risks associated with sports participation, overuse injuries continue to increase in youth athlete populations.[1,19-22,24,59] Physeal injuries are one type of overuse injury exclusive to pediatric populations that are most often sustained during athletic practice or competition.[14,15,18-20,22-24,26,34,41,48,55,56,76,81,87,93,102,119,141,144,145,152] While specific mechanisms of injury are heterogeneous and differ by sport, the physis, as the weakest part of the bone, is a site highly prone to injury in youth athletes.[18,19,21,38]

Overuse physeal injuries develop in response to excess stress placed on immature bony and soft tissue structures.[19-24,34,35,41,42,45,47,48,56,59,74,77,79,87,102,106,114,131] Rapid physical changes combined with repetitive sport-related tasks such as running and overhead throwing are frequently associated with the development of physeal injuries in youth athletes.[19,21,26] The gradual nature of this injury progression provides clinicians with multiple opportunities for effective intervention. Overuse physeal injuries are, in theory, preventable. Prevention and treatment strategies should be population-specific, taking into account previously established risk factors and clinical impairments observed in youth athletes.[21] The purpose of this work was to review and aggregate the best available evidence concerning recommended prevention and treatment strategies for overuse physeal injuries for application to clinical practice.

2.3 Methods

2.3.a Literature Review Methods and Article Identification

An electronic literature search was performed accessing papers published from January 1950 to May 2015 in the PubMed and all EBSCOhost databases. Search terms included *epiphyseal injury, epiphyseal plate injury, pediatric sports injury and physeal sports injury*. Additional searches in the aforementioned databases were performed using the terms *little league shoulder, gymnast wrist, little league elbow, lower extremity physeal injury, osgood schlatter disease, sever's disease and sinding-larsen-johansson disease* as they were the most commonly reported mechanisms of injury during the primary search. Only English language articles published in peer-reviewed journals with an emphasis on human participants were initially included. Articles were also required to meet *Level IV* standards or higher based on criteria developed by the Oxford Centre for Evidence-based Medicine (OCEBM). Abstracts and non-published works were not included. Based on these search criteria, 3,663 articles were located. Using the Preferred

Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, studies were selected based on appropriateness of topic and full text options.[104] All clinical commentaries and review articles were omitted. A total of 24 original research studies were included in this systematic review (Figure 2.1).

2.3.b Eligibility Criteria

Article selection was based on repetitive stress as a mechanism of injury in young athletes. Case reports, case series and cohort studies that described non-sport related mechanisms of injury, such as falls, were not included in this review. Acute sport-related injuries were also excluded. The scope of this systematic review was limited to overuse physeal injuries sustained during athletic competition.

2.4 Results

Twenty-four studies were included in this systematic review (Tables 2.1 and 2.2).[2,5,9,10,13,27,34,45,47,59,60,66,79,82,83,88,103,114,115,117,130,131,147] Thirty-three percent of studies included descriptions of known physeal injury risk factors while only 8% percent of studies used those factors to outline effective prevention strategies.[10,27,34,45,79,117,130,147] Eighty-eight percent of studies included data describing treatment strategies following an overuse physeal injury.[2,9,10,13,27,34,45,47,59,66,82,83,88,103,114,115,117,131,147,150] Review of current evidence suggests that more emphasis has been placed on the treatment of overuse physeal injuries and that further research is needed to establish effective prevention strategies for these diagnoses.

Risk factors common to both lower extremity (LE) and upper extremity (UE) physeal injuries include age, physical characteristics, growth patterns and training volume.[19,21,26] While limited evidence was available describing effective prevention strategies in this population, studies did emphasize that youth athletes should engage in minimum periods of active rest following their competition cycles.[19,38] Adequate physical training and variation in sport-specific tasks were also encouraged.[19,39] Treatment strategies following an overuse physeal injury included varying periods of active rest and when necessary, immobilization of the affected joint.[2,5,9,10,27,47,59,66,82,83,103,115,150] Gradual return to physical training and conditioning tasks was recommended prior to full return to sport.[5,9,79,82]

2.4.a Lower Extremity Injuries

Overuse physeal injuries in the LE typically occur when excess stress is placed across areas with major tendons insertions.[11,19] Osgood-Schlatter Disease, Sever's Disease and Sinding-Larsen-Johansson Syndrome are 3 of the most common overuse physeal injuries sustained during childhood.[15,93,96] The first two syndromes account for a staggering 18% of all pediatric overuse injuries reported in the literature.[93]

Osgood-Schlatter Disease is described as chronic apophysitis of the patellar tendon where it inserts on the tibial tuberosity apophysis. It is typically observed in girls ages 8-13 years and boys ages 10-15 years (Figure 2.3).[34] The same inflammatory process occurs with Sever's Disease but at the Achilles tendon insertion into the vertical calcaneal apophysis.[117] This condition appears to present more often in young boys between the ages of 8 and 12 years old.[74] Sinding-Larsen-Johansson Syndrome has a similar etiology but develops at the junction of the inferior pole of the patella and the proximal portion of the patellar tendon.[150] While this syndrome appears less frequently in the literature than the previous two, Sinding-Larsen-Johansson Syndrome does occur in youth athletes between the ages 10-15 years, limiting their function and participation levels (Table 2.1).[150]

Prevention strategies in the literature emphasize the correction of modifiable risk factors such as deficits in trunk and LE flexibility, which is often attributed to rapid changes in physical growth common during childhood and adolescence.[19,21,26,39,150] Programs designed to enhance cardiovascular endurance and correct physical training errors are also recommended to prevent these types of injuries.[34,38,79] Following an overuse physeal injury in the LE, 50% of studies recommend a 3-5 month period of active rest with complete cessation of sport-specific activities.[9,59,66,82,103,117,150] Twenty-one percent of studies suggest activity modifications may be appropriate based on the symptom presentation of the athlete, thereby limiting their total time away from sport.[9,82,117] Lower extremity stretching and conditioning programs were also used in 21% of the studies as either a stand alone treatment or in conjunction with additional strategies.[34,79,117] Several studies reported joint immobilization and surgical intervention for long standing physeal injuries related to overuse, however these strategies were only employed in severe cases.[59,66,83,103,114,117] Irrespective of the treatment strategy used, an athlete should not fully return to sport until symptom resolution has occurred. No studies to date have examined or compared the effectiveness of these treatments in youth athlete populations.[134]

2.4.b Upper Extremity Injuries

Overuse physeal injuries in the UE occur due to excess compression or traction forces placed across a joint during sport.[19,41] Gymnast Wrist, Little League Shoulder and Little League Elbow are 3 UE physeal injuries that are highly prevalent and described frequently in the pediatric sports literature.[2,5,10,13,27,47,60,79,115,117,131,147] Seventy nine percent of youth gymnasts report wrist pain during practice or competition while 32% of youth baseball pitchers report arm pain while throwing.[41,90,91]

Gymnast wrist occurs in response to the premature closure of the distal radial physis following excessive compression loads during UE weight bearing.[24,88] Gymnastics is one of the few sports that repeatedly performs closed chain weight bearing activities on both their upper and lower extremities.[3,16,20,22,23,35,41,42] This injury is typically seen in athletes between the ages of 10 and 14 years old (Table 2.2).[41] Little League Shoulder has been described in the literature as a widening of the proximal humeral epiphysis or epiphysiolysis (Figure 2.4). It is most often seen in the dominant shoulder and is thought to occur secondary to the repetitive rotational and traction stresses associated with overhead throwing.[2,5,10,14,27,47,115,147] Little League Elbow is a term often used to describe a variety of physeal and cartilaginous injuries at the pediatric elbow.[18,19,21,55,60,77] By definition, Little League Elbow is a repetitive traction injury to the medial epicondylar apophysis (Figure 2.5).[55] Diagnoses of Little League Shoulder and Little League Elbow are most often made following reports of persistent arm pain and loss of function in youth baseball pitchers between the ages of 11 and 15 years old (Table 2.2).[27,77,115]

Risk factors associated with the development of Gymnast Wrist include consistent UE loading and timing of growth spurts.[40] Studies suggest that participation in repetitive UE weight bearing tasks, especially during periods of rapid physical growth, is directly associated with this highly prevalent, population-specific injury.[19,37,40-42] Risk factors related to the development of Little League Shoulder and Little League Elbow are similar. Excessive game, season and yearly pitch counts and pitching while fatigued are factors that have been associated with shoulder and elbow dysfunction in youth baseball players.[90,91] Pitch type and selection are also important for the health of this population. Youth baseball players who reported throwing breaking pitches such as curveballs or sliders over the course of the season were more at risk to develop shoulder and elbow pain when compared to those who did not.[90] Anthropometric measures such as increased height and weight also impacted injury risk but were more significant to the development of elbow pathology than shoulder pathology.[91]

Despite the lack of epidemiological data concerning Gymnast Wrist, multiple prevention strategies have been suggested in the literature.[37,38,40] The gradual progression and variation of training loads is imperative to limit the volume of compressive forces sustained through the distal radial physis.[37,39,40] Studies suggest that coaches and parents should be cognizant of rapid changes in growth, as the athlete is most at risk for overuse physeal injuries during this period.[37,39] In an effort to prevent Little League Shoulder and Little League Elbow, USA Baseball implemented yearly, seasonal and game pitch count limitations based on an athlete's age at the time of competition.[90,91,116] These recommendations were designed to decrease an athlete's risk for injury by limiting excessive stress and fatigue during sports participation.[89-91]

Treatment strategies for all three overuse physeal injuries center around an extended period of active rest. Following an injury, 50% of studies recommend active rest from sport-specific training to ensure adequate healing and symptom resolution.[2,5,27,47,115,117] Recommended periods of active rest range from 4-6 weeks for a diagnosis of Gymnast Wrist or Little League Elbow to 3-5 months for athletes with Little League Shoulder.[2,27,40,115,140] In severe cases of Little League Elbow, joint immobilization and/or surgical intervention have been employed to ensure optimal functional outcomes.[78,119,125] However, an extended period of active rest remains the main treatment of choice for overuse physeal injuries in the UE.

2.5 Discussion

The main purposes of this systematic review were to identify known risk factors associated with overuse physeal injuries and to determine which prevention and treatment strategies were most effective and supported by the evidence. Physeal injuries represent approximately 15% of all pediatric sports injuries currently reported in the literature.[19] The physis, as the weakest physiologic structure in a young athlete, is particularly susceptible to overuse injuries.[14,15,18-26,34,40,48,55,56,76,81,87,93,102,119,141,144,145,152] As participation in youth sports continues to increase, clinicians should become cognizant of the risk factors, prevention strategies and treatment options associated with overuse physeal injuries.[14,15,19,21,22,55,144,145]

2.5.a Risk Factors

Risk factors associated with participation in youth sports have been reported throughout the literature, however no research studies have examined injury risk with respect to physeal injuries.[21] Physeal injuries are exclusive to skeletally immature individuals suggesting that modifiable and non-modifiable risk factors are specific to this population.[21,26,34,35,56,79,100,134]

Non-modifiable risk factors for overuse injuries can include timing of accelerated growth spurts, chronological age, body size and history of previous injury.[21,38,40] Previous injury is the strongest predictor for the development of future injuries supported by the literature.[21,26,126,149] Studies show that athletes who reported a prior injury were at a much higher risk to sustain an injury when compared to a previously healthy cohort.[149] Modifiable risk factors such as flexibility, strength, training volume and coaching styles also impact overall injury risk in youth and adolescent athletes. Multiple studies suggest that excessive training loads often lead to physical fatigue in youth athletes. Continued participation in sport once fatigued can damage an athlete's physical development thereby illustrating the importance of responsible coaching, especially during the early years of sport.[21,38,40,76]

2.5.b Prevention and Treatment Strategies

Injury prevention strategies for youth and adolescent athletes focus on limiting time spent participating in sport as well as encouraging 2-3 months of scheduled rest away from training and competition.[38,121] This is designed to mediate the effects of repetitive risk-prone activities on physically maturing bodies. Pitch count regulations, which are enforced by the governing bodies in youth baseball, is one notable attempt at preventing upper extremity overuse injuries at the policy level.[90,91,135,139] Multiple studies have also recommended that clinicians monitor known risk factors such as anthropometric (i.e. height and weight) and physical characteristics (i.e. range of motion and strength) as youth athletes mature over time.[34,37,38,136,148] Multiple programs designed to improve flexibility, strength and balance deficits have been shown to have protective effects against injuries in this population.[21,25,94,95,120,138]

The most widely accepted treatment strategy following any physeal injury is an extended period of active rest.[3,10,19,27,30,74,77,114,115,134] Recommended durations of active rest vary from 4-6 weeks to 3-5 months depending on by diagnosis, sport and severity of symptoms.[26,27,77] During this time, strategies can include changes in field position to limit throwing in the cases of Little League Shoulder and Little League Elbow or the recommendation of no running for a specified period of time in athletes with Osgood-Schlatter, Sinding-Larsen-Johansson's or Sever's Disease. In most cases, non-symptomatic activities such as hitting a baseball or footwork drills in soccer can be continued. This allows young athletes to continue training without prolonging their recovery by re-aggravating the affected joint.

During a period of active rest, conservative measures such as physical therapy can prove beneficial. Once the pain has subsided, clinicians can begin to restore the necessary flexibility, strength and neuromuscular control required to participate safely in sport.[2,3,5,13,20,22-25,27,29,35,40,42,47,78,79,115,132,140] Progressive strength training programs, lasting approximately 6-8 weeks, can be augmented with return to throwing or running programs when appropriate.[77] The rehabilitation programs reported in the literature were vague and lacked return to sport criteria. Future research should focus on the development of age- and injury-specific return to sport progressions designed to provide clinicians with evidence-based guidelines to return their athletes safely back to sport.

2.5.c Limitations

The main limitation of this systematic review was the lack of experimental and epidemiological data concerning overuse injuries in youth sports. Review studies typically described pediatric sports injuries in general terms with little respect to injury type. The current evidence surrounding risk factors, prevention and treatment strategies for overuse injuries in youth sports was primarily limited to review studies and *Level III and IV* publications. The paucity of high quality evidence combined with strict inclusion criteria appeared to impact the study selection process. A variety of search terms were used however a disproportionate number of studies featured Little League Shoulder as a diagnosis of interest. This selection bias towards overuse physeal injuries in the UE may have influenced the generalizability of the clinical recommendations made in this systematic review.

2.5.d Knowledge Gaps

The lack of high quality, patient-oriented research in younger athlete populations and the absence of research describing physeal injuries pose notable gaps in the literature. These gaps include minimal data establishing the incidence, prevalence and severity of overuse injuries in youth athletes, especially with respect to physeal involvement.[91,116] No original research studies have clearly defined physeal injuries at this time. Also, little is known about the effects of population-specific risk factors, like growth-related changes and training volume, on the development of injuries in skeletally immature individuals. Future studies should 1) seek to establish a clear definition of physeal injuries in sport, and 2) understand the mechanisms and risk factors associated with their development. This will provide the foundation for more effective prevention and treatment strategies at the policy level, including the paradigm-shifting concept of scheduled periods of rest from sport. Scheduled rest provides youth athletes the time they need to physically and mentally recover from the rigors of competitive sport.

2.6 Conclusion

Overuse physeal injuries are multi-factorial in nature.[95] Periods of accelerated growth, chronological age, skeletal maturity and history of previous injury can predispose young athletes to repetitive stress injuries.[95] Modifiable risk factors such as flexibility, strength and training volume should be regularly monitored in an effort to limit risk-prone activities and prevent injuries when possible.[21,26,34,35,56,79,134,149]

The most effective treatment strategy following overuse physeal injuries is an extended period of active rest. Following symptom resolution, clinicians can begin to restore function through improvements in flexibility, strength and neuromuscular control.[2,3,5,13,20,22-24,26,27,29,35,41,42,47,78,79,132,140] Progressive strength training programs should include gradual return to throwing or running programs when appropriate.[77] Return to sport timelines typically range from 4-6 weeks in most cases, but can extend to 3-5 months when symptoms persist.[27,77,83]

2.7 Clinical Recommendations

The most widely accepted treatment option following any physeal injury is an extended period of active rest and when necessary joint immobilization. Once the pain has subsided, emphasis on the restoration of flexibility, strength and sport-specific endurance is appropriate.[3,10,19,27,30,74,76,114,115,134]

Strength-of-Recommendation Taxonomy: C

1) Modifications such as implementing sport-specific flexibility and strength programs as well as limiting training and competition volumes (i.e. pitch counts) are 2 strategies to avoid overuse and fatigue-related injuries. This is especially important during periods of rapid growth.[21,25,26,77,90,91,95,116,120,127,135,138,140,148]

   Strength-of-Recommendation Taxonomy: B

2) Regular monitoring of anthropometric (i.e. height and weight) and physical characteristics (i.e. range of motion and strength) in youth athletes may prove preventative as deficits have been linked to both UE and LE injuries in multiple sporting events.[30,77,116,148,152]

Strength-of-Recommendation Taxonomy: C

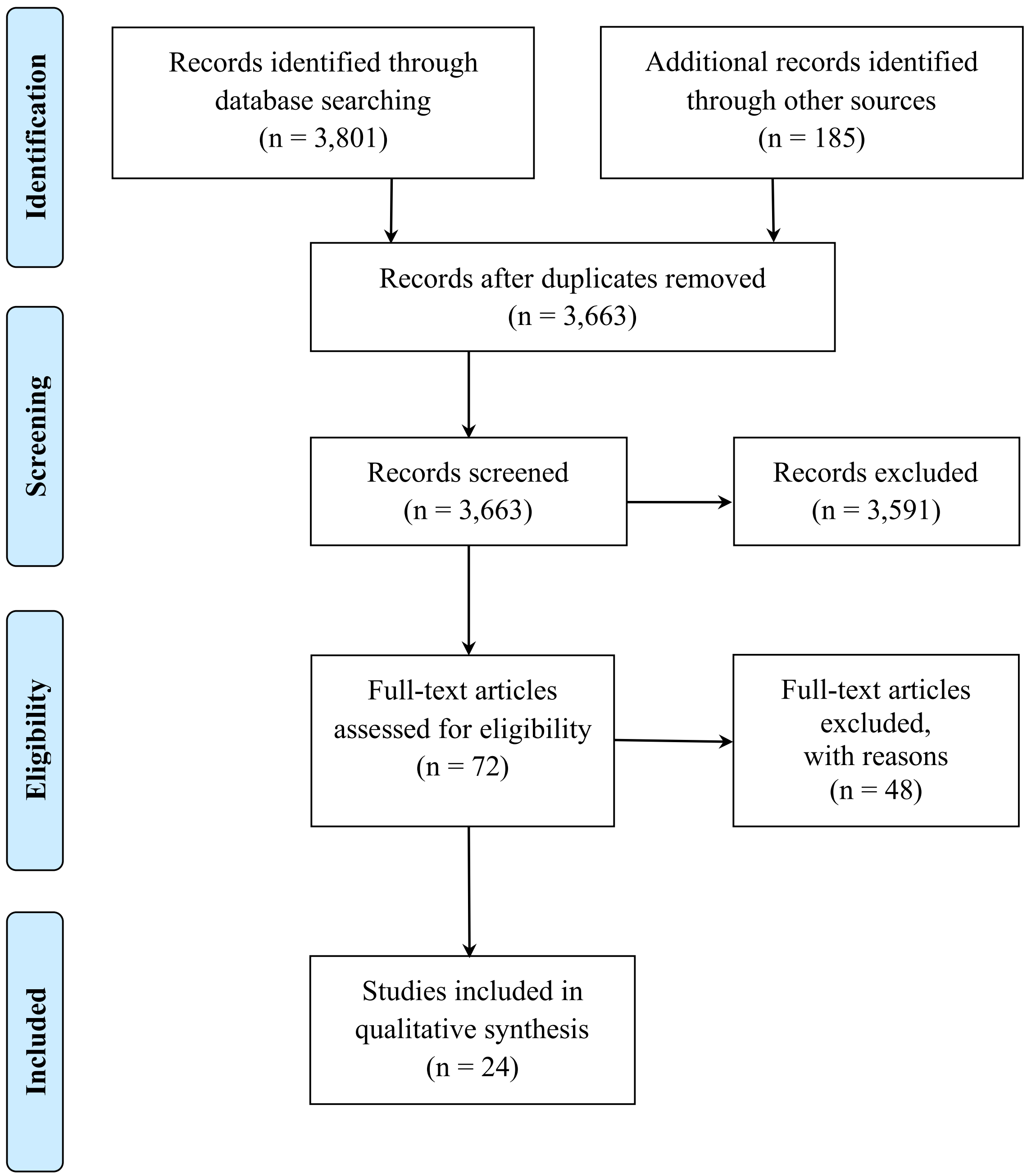

Figure 2.1 PRISMA Flow Diagram[104]

Strength of Recommendations	Definition
A	Recommendation based on consistent, good quality patient-oriented evidence* (morbidity, mortality, exercise and cognitive performance, physiologic responses).
B	Recommendation based on inconsistent or limited quality patient-oriented* evidence.
C	Recommendation based on consensus, usual practice, opinion, disease-oriented evidence* case series or studies of diagnosis, treatment, prevention, screening, or extrapolations from quasi-experimental research.

*Patient-oriented evidence measures outcomes that matter to patients: morbidity, mortality, symptom improvement, cost reduction, and quality of life. Disease-oriented evidence measures intermediate, physiologic, or surrogate end points that may or may not reflect improvements in patient outcomes (e.g.: blood pressure, blood chemistry, physiologic function, pathologic findings).

Figure 2.2 Strength-of-Recommendation Taxonomy (SORT) Diagram[49]

Figure 2.3 Radiograph of 13-year-old male football player with Osgood-Schlatter Disease

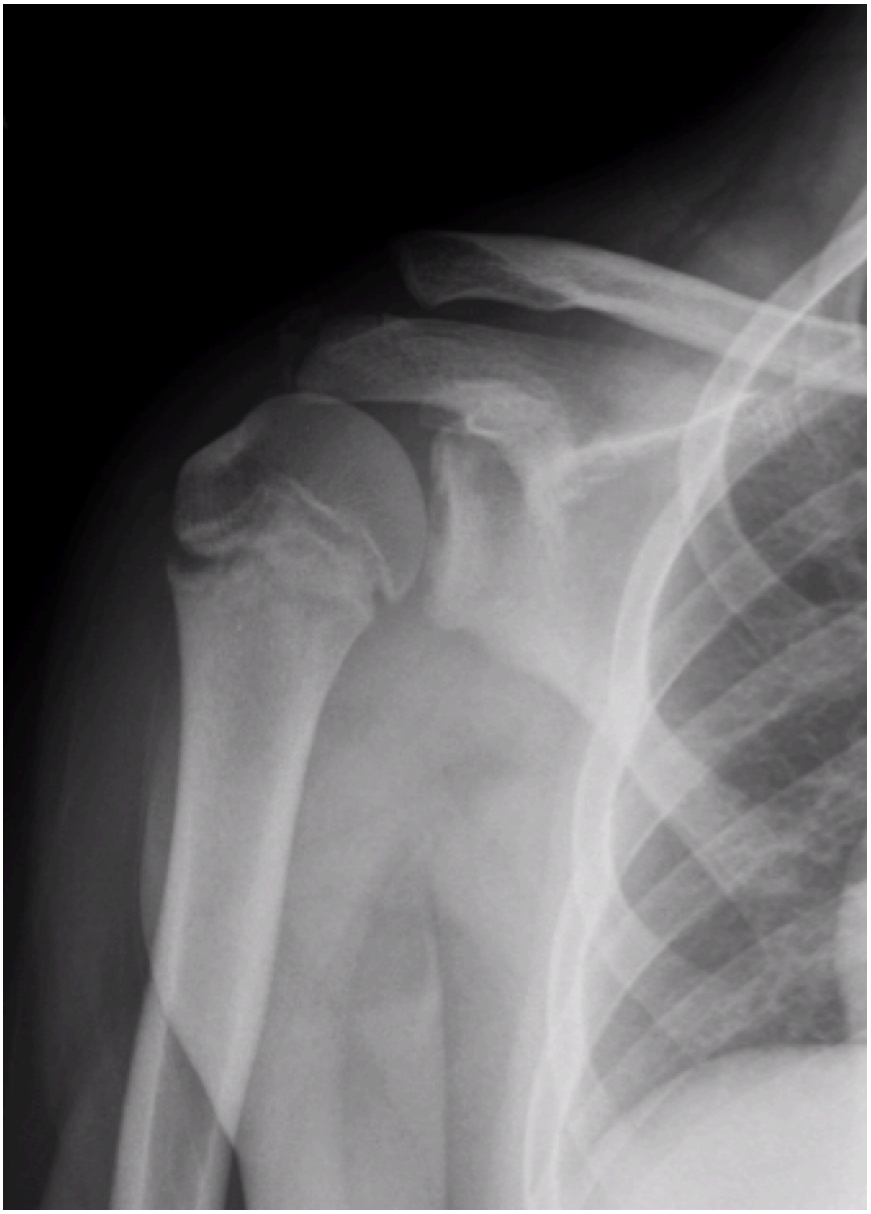

Figure 2.4 Radiograph of 14-year-old male baseball player with Little League Shoulder

Figure 2.5 Radiograph of 13-year-old male baseball player with Little League Elbow

Table 2.1. Studies that Report Lower Extremity Physeal Injuries

Author	Level of Evidence (OCEBM)	Sample Size	Age (yrs)	Injury Site	Sport	Treatment Options
Beovich[9] (1988)	III	22	9 – 18	Proximal tibial tubercle	Multiple	Activity modifications (20); Active rest (2)
de Lucena[34] (2010)	III	954	12 – 15	Proximal tibial tubercle	Multiple	Stretching program
Doral[45] (2005)	IV	1	16	Anterior superior iliac spine	Soccer	Surgical intervention
Hajdu[59] (2000)	IV	7	13 – 16	Proximal tibial tubercle	Ball games, skiing	Active rest (1); Surgical intervention (6)
Hussain[66] (1996)	III	261	11 – 18	Proximal tibial tubercle	Multiple	Active rest & NSAIDs (237); Surgical intervention (24)
Kolt[79] (1999)	III	43	11 – 19	Multiple sites	Gymnastics	Physical conditioning program
Kujala[82] (1985)	III	68	9 – 18	Proximal tibial tubercle	Multiple	Active rest 3 months; Activity modifications 7 months
Laor[83] (2006)	IV	6	8 – 15	Distal femur, proximal tibia, proximal fibula	Football, basketball, gymnastics, other	Joint immobilization 1-5 wks
Liebling[88] (1995)	IV	1	13	Distal femur, proximal tibia	Baseball	None
Mital[103] (1980)	III	118	9 – 18	Proximal tibial tubercle	Multiple	Active rest/Joint immobilization (104); Surgical intervention (14)
Nanni[114] (2005)	IV	1	15	Proximal tibia	Rugby	Surgical intervention

Orava[117] (1982)	III	185	9 – 26	Multiple sites	Multiple	Varied
Rossi[130] (2001)	III	203	11 – 18	Pelvic apophyses	Soccer, gymnastics, fencing, tennis	None
Valentino[150] (2012)	IV	1	13	Inferior patellar pole	Football	Active rest 5 months

Table 2.2. Studies that Report Upper Extremity Physeal Injuries

Author	Level of Evidence (OCEBM)	Sample Size	Age (yrs)	Injury Site	Sport	Treatment Options
Akgul[2] (2011)	IV	1	13	Proximal humerus	Non-athlete	Active rest 4 months
Anton[5] (2010)	IV	1	13	Proximal humerus	Baseball	Active rest, Physical therapy
Binder[10] (2011)	III	72	8 – 13	Proximal humerus	Unknown	Joint immobilization 1-4 wks (57); Surgical intervention (15)
Boyd[13] (1997)	IV	1	15	Proximal humerus	Badminton	None
Carson[27] (1998)	III	23	14	Proximal humerus	Baseball	Active rest 3 months
Drescher[47] (2004)	IV	1	12	Proximal humerus	Cricket	Joint immobilization 3 wks; Active rest 3 months
Hang[60] (2004)	III	343	8 – 12	Distal humerus	Baseball	None
Kolt[79] (1999)	III	43	11 – 19	Multiple sites	Gymnastics	Physical conditioning program
Obembe[115] (2007)	IV	4	11 – 15	Proximal humerus	Baseball, Tennis	Active rest 3 months
Orava[117] (1982)	III	185	9 – 26	Multiple sites	Multiple	Varied
Roy[131] (1985)	IV	21	11 – 18	Distal radius	Gymnastics	None
Torg[147] (1972)	IV	1	12	Proximal humerus	Baseball	None

CHAPTER 3

METHODS

3.1 Research Design

This study prospectively followed a cohort of competitive youth baseball players over the course of a 6-month season (Figure 3.1). Approval for this study was received from the University of South Carolina's Institutional Review Board (IRB). The research team complied with all rules, regulations and training requirements put forth by the IRB.

3.2 Study Setting

This study was conducted at local baseball clubs (Hit House, Elite Baseball and Southern Athletics), as well as the Greenville and Northwood Little Leagues. ATI Physical Therapy and Steadman-Hawkins Clinic of the Carolinas facilities were also used during this study.

3.3 Study Subjects

Two hundred and sixty-one competitive baseball players were recruited for this study based on sample size calculations with 80% power and an alpha level of 0.05. Inclusion criteria required that all participants be male, between 9 and 12 years of age and uninjured at the time of baseline data collection. Players were excluded from the study if they reported any current injuries that restricted their ability to participate in baseball activities or if they reported a shoulder or elbow injury that required medical attention during the 3 months prior to the start of the study. Recruitment strategies were based on well-established community relationships with the coaches and parents of several local baseball clubs as well as the Greenville and Northwood Little League Baseball programs. To increase retention and response rates over the course of a 6-month follow up period, the primary investigator emphasized the importance of both team coaches' and parents' participation in the bi-monthly online surveys. The primary investigator also acted as the established point of entry into the medical community, for coaches and parents, when a baseball player suffered a baseball-related upper extremity injury.

3.4 Procedures

An online survey (see Appendix A), in conjunction with a baseline physical examination (see Appendix B), was completed during the course of the competitive baseball season to identify potential risk factors for injury in this population (Table 3.1). Players' training and playing histories, as well as any injuries sustained, was be tracked every 2 weeks over the course of a 6-month period (Table 3.1). Team coaches and participants' parents were contacted every 2 weeks via online surveys, phone conversations and in person visits in an effort to improve response rates as well as corroborate data reported for each player. All baseball players who reported baseball-related upper extremity impairments underwent a subsequent physical examination performed by the primary investigator to confirm the presence of an injury. A second exam was also performed in a subset of youth players to assess any changes from the baseline physical data recorded earlier in the season. The subsequent examination included height, weight, shoulder and elbow range of motion (ROM) and isometric shoulder strength.

Height and weight measurements for each participant were measured using a portable stadiometer and digital weight scale, respectively. Humeral torsion, passive shoulder and elbow ROM, isometric shoulder strength and ulnar length were assessed in both the dominant and non-dominant arms of each participant. Two values of each measure were recorded per arm.

Humeral torsion was measured using a Sonosite-Edge (Sonosite Inc, Bothell, WA, USA) ultrasonography unit with a 6 cm linear array transducer (6-15 MHz). Examiners used a previously validated indirect ultrasonography method to assess the differences in bony development between the dominant and non-dominant arms.[57,110-112,118,153-155] All measurements were taken in the supine position with the arm at 90° of abduction and the elbow at 90° of flexion. One examiner passively rotated the arm until the apices of the greater and lesser tuberosities were parallel in the coronal plane. A second examiner placed a digital inclinometer (Fabrication Enterprises Inc, White Plains, NY, USA) along the ulnar border and recorded the corresponding angle of the forearm. In this method, the larger angle indicated less humeral retrotorsion.[7,111,153,161] Acceptable intra-rater reliability for measurement of HT was established prior to the data collection ($ICC_{2,1}$ = 0.92-0.99; SEM = 1.7°-3.8°).

Shoulder external rotation (ER) and internal rotation (IR) ROM was assessed bilaterally in supine using a digital inclinometer and methods previously reported in the literature.[7,136,158] The scapula was stabilized at the corocoid process with the arm at 90° of abduction and elbow flexion. A towel roll was placed under the distal humerus to maintain the scapular plane. The arm was then passively rotated to end range for measurement. No overpressure was applied. Horizontal adduction ROM was assessed with the athlete in the supine position. Full scapular retraction was maintained with stabilization at the lateral scapula, while the examiner horizontally adducted the arm maintaining neutral humeral rotation until resistance was felt. A digital inclinometer was used to assess the angle between the humerus and the horizontal plane of the body.[7,136] Elbow extension ROM was assessed with the athlete in the supine position with the arm in 90° of abduction and neutral rotation. A towel roll was placed under the distal humerus to maintain the scapular plane. A digital inclinometer was placed along the anterior surface of the forearm in the plane of the acromion using the radial styloid process as the primary landmark. The angle of the radial styloid process relative to the parallel line of the acromion was recorded. Positive values indicated elbow hyperextension. Acceptable intra-rater reliability was established for all ROM measurements prior to data collection ($ICC_{2,1}$ = 0.92-0.99; SEM = 1.3°-3.8°). An average of 2 trials was used for each measure in data analysis. Total arc of motion was calculated by adding mean ER ROM with IR ROM for the dominant and non-dominant shoulders, respectively. Side-to-side differences were calculated for each ROM variable by subtracting dominant values from the non-dominant values.

Isometric shoulder strength was assessed bilaterally using a Lafayette Manual Muscle Tester hand-held dynamometer (Lafayette Instrument Company, Lafayette, IN, USA) and previously reported methods.[17] Isometric shoulder strength measures included scaption at 90°, ER at 0°, ER at 90° and IR at 90° for the dominant and non-dominant arms. Make tests were used for each isometric strength measure based on higher reliability when compared to break tests in hand-held dynamometers.[146] Scaption strength was measured in the seated position. The arm was abducted to 90° and then horizontally adducted to 45° with neutral shoulder rotation. The hand-held dynamometer was placed 5 cm distal to the cubital fossa. The participant raised the arm perpendicular to the floor using maximum effort.[17] External rotation at 0° was assessed with the arm in 0° of shoulder abduction with a towel roll placed under the axilla. The elbow was positioned in 90° of flexion with neutral forearm rotation. The hand-held dynamometer was placed on the dorsal aspect of the forearm, 2 cm proximal to ulnar styloid process. The participant then externally rotated the arm with maximum effort.[17] External rotation at 90° was measured with the shoulder in 90° of abduction, 90° of ER and 90° of elbow flexion. A towel roll was placed under the distal humerus to maintain the arm in the plane of the body. The dynamometer was placed on the dorsal aspect of the forearm, 2 cm proximal to ulnar styloid process. The participant then externally rotated the arm with maximum effort.[17,46] Internal rotation at 90° was assessed in a similar fashion to ER at 90°, however the shoulder was in a state of neutral rotation and the dynamometer was placed on the volar aspect of the forearm. The participant was asked to maximally internally rotate his arm.[17] Acceptable intra-rater reliability for all isometric shoulder strength measures was established prior to the data collection ($ICC_{2,1}$ = 0.94-0.99; SEM = 1.3-3.6 lbs). To ensure that minimal detectable change (MDC) exceeded the standard error of measure (SEM), intra-rate reliability was re-calculated using the first 10 participants' data. Ulnar length measurements were recorded for the dominant (D) and non-dominant (ND) arms and used to calculate both ER and IR torque values for each participant.[68] Isometric shoulder strength was then normalized prior to data analysis using 5 separate methods: body mass, body mass index (BMI), height, torque and the Trakis Method (Table 3.2).[148]

Throwing performance was assessed using ball velocity during an overhead throw. This measure was assessed within 10 days of baseline data collection in a subset of 80 participants. Following a warm up period during team practice, participants were asked to throw 3 balls from a distance of 46 feet on flat ground to a specified target. A Stalker radar gun was used to record the velocity of each throw in miles per hour (mph). Only accurate ball velocities were recorded and then used in data analyses to determine if isometric shoulder strength and throwing performance were related.

Baseball-related upper extremity injuries will be defined as any shoulder or elbow impairment that resulted in either: 1) an athlete missing $\geq$1 practice(s) or game(s), or 2) an athlete experiencing a reduction in their performance (i.e. decreased ball control or velocity) or change in position (i.e. moving from pitcher to 1st base) related to the UE complaint.[43,75,113,137] Injuries were originally identified via self-report from the team coaches and the participant's parents using the RedCap online survey system, phone conversations and in person interviews. Players, parents and coaches were also encouraged to contact the research team if any concerns arose throughout the study. Once identified, all baseball-related upper extremity injuries were examined by the primary investigator, a licensed physical therapist and when necessary, referred to a board certified, fellowship-trained, sports medicine physician at the Steadman Hawkins Clinic of the Carolinas for further evaluation. All injured baseball players who were examined by a physician may have received x-rays as part of their evaluation per typical standard of care. Any damage to the physis or 'growth plate' at the shoulder or elbow was confirmed through physician evaluation and diagnosis. All costs related to physician visits, including diagnostic imaging, was billed to the players' insurance companies. This study was not responsible for any medical expenses incurred as a result of a baseball-related injury.

3.5 Statistical Analyses

3.5.a Specific Aim 1

Determine the incidence of baseball-related upper extremity injuries in a cohort of 9-12 year old male baseball players.

Specific incidence was defined as the number of baseball-related upper extremity injuries recorded per 1,000 athletic exposures. As stated previously, an athletic exposure was defined as 1 organized team practice or game that an athlete participated in. Means and standard deviations were calculated for each variable based on injury status.

Injury status was the main outcome of interest used in the power calculations for Specific Aim 1. The number of baseball-related upper extremity injuries necessary to statistically compare injured and uninjured groups was approximately 50 baseball players. Based on previous research, a baseball-related injury rate of 0.18 was expected, which indicated that a sample size of 275 baseball players would have be adequate to capture the target population of youth players who sustain baseball-related injuries.[31,137] Those calculations assumed a 2-sided alpha level of 0.05. Based on that analysis, the current study had sufficient power (100%) to assess upper extremity injury risk in a cohort of 9-12 year old male baseball players.

3.5.b Specific Aim 2

Compare the measurement properties of normalized isometric shoulder strength, by 5 separate methods, for use as a multi-faceted clinical assessment tool that was responsive to changes in physical growth and development over time in a cohort of 9-12 year old male baseball players.

The main outcomes of interest were the measurement properties of each of the 5 normalization methods (body mass, BMI, height, torque and the Trakis method[148]) which included test-retest reliability of each strength measure, the ability to detect changes in shoulder strength over time and the strength of the relationship between shoulder strength and ball velocity as a measure of throwing performance. Means and standard deviations were calculated for each normalized isometric shoulder strength measures by method. Humeral torsion and shoulder ROM measures were also assessed as they were thought to potentially influence isometric shoulder strength in youth baseball players. When analyzed, no significant relationships were observed between isometric shoulder strength and humeral torsion or isometric shoulder strength and shoulder ROM in this population.

Reliability was assessed for all baseline and follow-up strength measures using intraclass correlation coefficients (ICC) with corresponding 95% confidence intervals (CI).[122] Standard errors of measurement (SEM) were also calculated to determine the absolute reliability of each strength measure using the largest SD in the formula SD x $\sqrt{1 - \text{ICC}}$.[122] Individual SEMs were then used to calculate corresponding minimal detectable change (MDC_{95}) values for each of the normalized strength measures using the formula SEM x 1.96 x $\sqrt{2}$.[122] Repeated measures analyses of variance (ANOVA) were conducted to compare changes in isometric shoulder strength at 2 time points (baseline and follow-up) after co-varying for physical growth and body size. Effect sizes were calculated to identify the magnitude of change detected between the 2 time points for each of the normalized strength measures. Linear regression models were used to examine the relationships between the normalized isometric shoulder strength measures and ball velocity in youth baseball players. The method with the most consistent measurement properties for normalizing isometric shoulder strength in youth baseball players was determined based on each measure's test-retest reliability, ability to detect changes over time and strength of association with ball velocity. Statistical significance was set a priori at $\alpha=0.05$. All statistical analyses were performed using SPSS Statistics 21.0 (SPSS Inc., Chicago, IL, USA) software.

The study team demonstrated good reliability for all the variables of interest including isometric shoulder strength with a standard error of measurement of less than 5% for each measure. Only isometric shoulder strength data was presented, as they were the main variables of interest and represented the most variable data in the analyses. The small to moderate effect sizes used in the power calculations below were estimated using data from previous studies. These calculations assumed a 2-sided alpha level of 0.05 and showed that the current study was sufficiently powered (>91% for the isometric force production variables of interest).

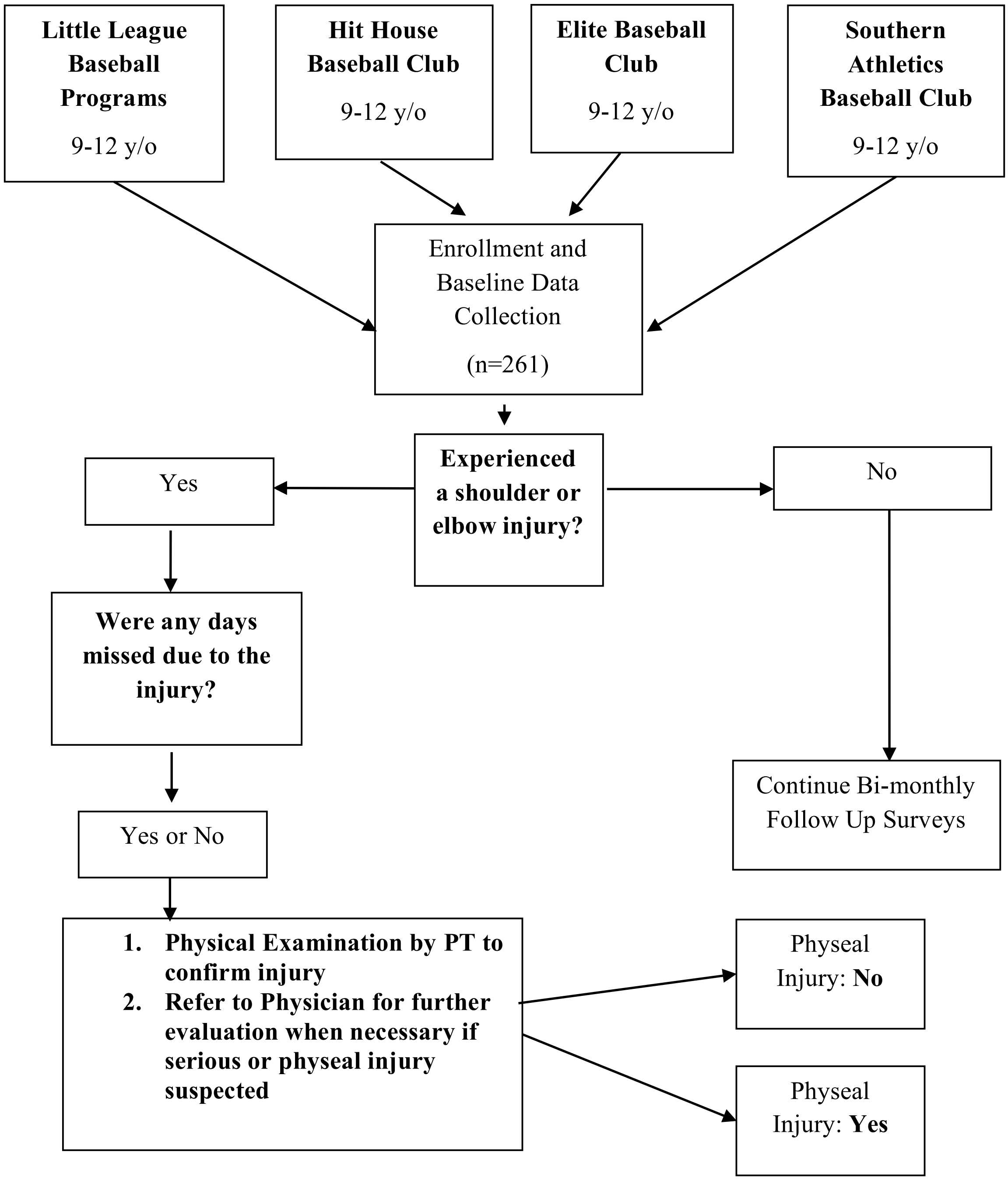

Figure 3.1. Prospective Cohort Study Design Flowchart

Table 3.1. Data Collection Measures

Dependent Variable Name	Definition	Collection Method
Upper Extremity Injury	Any shoulder or elbow impairment that resulted in either: 1) athlete missing ≥1 practice(s) or game(s), or 2) athlete experiencing a reduction in their performance (i.e. decreased ball control or velocity) or change in position (i.e. moving from pitcher to 1st base) related to the UE complaint.[43,75,113,137]	Self-report followed by PT examination and physician examination when necessary
Physeal Injury	An injury at the shoulder or elbow joint with physician confirmed damage to the corresponding physis[18]	Physician evaluation and diagnosis
Independent Variable Name	**Definition**	**Collection Method**
Athletic Exposure	1 organized team practice or game[137]	Bi-monthly self report from coaches and parents via online survey system and phone responses
Age (years)	= Date of data collection – date of birth	Date of birth
Height (cm)	Measured to the nearest 0.5 cm	Stadiometer
Weight (lbs)	Measured to the 1st decimal place (ex: 119.1 lbs)	Digital scale
Position: Primary and Additional Positions	Position categories: 1 = pitcher 2 = position player	Self report
Sport Specialization Status	Self-Classification: Athletes were asked to identify as a specialized or multi-sport athlete Research-Based Classification: Athletes met at least 2/3 of the following research-based criteria: • Participated in organized baseball activities ≥ 8 months/year • Participated on ≥ 1 organized baseball team during the year • Participated in additional baseball-specific specialty training (i.e. pitching lessons)	Self report and Research-based criteria[8,71,72,84]

Participation in Additional Specialty Training	Training type categories: 1 = hitting lessons 2 = pitching lessons 3 = hitting or pitching lessons (baseball-specific) 4 = strength and agility training	Self report
Pain Level	0-10 with 10 being the highest level of pain	Pediatric Visual Analog Scale (VAS) score[159]
Humeral Torsion	The orientation of the humeral head relative to the transverse plan of the body[57,110-112,118,153-155]	Indirect method using diagnostic ultrasonography[110,153]
ROM: ER at 90°	Maximal shoulder ER with scapula stabilized and no overpressure[64,65,73,101,118,129,139,148,149,163]	Supine with digital inclinometer[64,65,139]
ROM: IR at 90°	Maximal shoulder IR with scapula stabilized and no overpressure[64,65,73,101,118,129,139,148,149,163]	Supine with digital inclinometer[64,65,139]
ROM: Elbow Extension	Maximal elbow extension with shoulder at 90° of abduction and no overpressure	Supine with digital inclinometer[64,65,139]
ROM: Horizontal Adduction	Maximal shoulder HA with scapula laterally stabilized and no overpressure[64,65,73,101,118,129,139,148,149,163]	Supine with digital inclinometer[64,65,139]
Isometric Strength: Scaption at 90°	Maximal force produced against manual resistance with upright posture and no trunk support[1,17,44,73,97,105,128,129,148,149]	Seated make test with HHD[17]
Isometric Strength: ER at 0°	Maximal force produced against manual resistance with upright posture and no trunk support[1,17,44,73,97,105,128,129,148,149]	Seated make test with HHD[17]
Isometric Strength: ER at 90°	Maximal force produced against manual resistance with shoulder at 90° abduction/90° ER[1,17,44,73,97,105,128,129,148,149]	Prone make test with HHD[17]
Isometric Strength: IR at 90°	Maximal force produced against manual resistance with shoulder at neutral rotation[1,17,44,46,73,97,105,128,129,148,149]	Prone make test with HHD[17]
Isometric Strength: ER:IR Ratio	$= \frac{\text{ER strength at 90°}}{\text{IR strength at 90°}}$	Prone make test with HHD[17]
Ulnar Length	Measurement between tip of olecranon process to most distal portion of ulnar styloid process[67,68]	Supine with shoulder in 90°/90° position with tape measure

Torque	Torque = isometric force production x lever arm[67,68]	= ER strength at 90° x ulnar length[67,68] = IR strength at 90° x ulnar length[67,68]
Throwing Performance: Ball velocity	Miles per hour (mph)	46 ft throw to a specified target with Stalker radar gun
Exposure to Training: # of practices/time period	Total # of practices played over the 6 month follow up period[137]	Bi-monthly self report from coaches and parents via online survey system and phone responses
Exposure to Training: # of games/time period	Total # of games played over the 6 month follow up period[137]	
Exposure to Training: # of months played/year	Total # of months where the athlete participated in organized baseball activities	
Previous History of Injury	Any previous injury that required medical attention or resulted in the athlete missing ≥1 practice or game[149]	Self report

Table 3.2. Normalized Isometric Shoulder Strength Calculations by Method

Method	Calculation
Body Mass (kg)	$= \frac{\text{Shoulder Strength Measure}}{\text{Body Mass}}$
BMI (kg/m^2)	$= \frac{\text{Shoulder Strength Measure}}{\text{BMI}}$
Height (cm)	$= \frac{\text{Shoulder Strength Measure}}{\text{Height}}$
Torque (Nm)	= Shoulder Strength Measure (N) x Ulnar Length (m)
ND Strength (%)[148]	$= \frac{\text{(Dominant Shoulder Strength – Non-Dominant Shoulder Strength)}}{\text{(Non-Dominant Shoulder Strength)}}$

Table 3.3. Aim 1 – A Priori Power Analyses Based on Expected Injury Rates[a]

	Sample Size	Total Injury Rate	Estimated # of Injuries	Estimated Power
Pilot Study	275	0.16	44	100%
Based on Previous Research[31,137]	275	0.18	50	100%

[a] Total injury rates determined using data from a pilot study and two previous research studies conducted in adolescent baseball players (13-18 years old).

Table 3.4. Aim 2 – A Priori Power Analyses Based on Isometric Shoulder Strength Measures[a]

Independent Measure	Effect Size[b]	Alpha Level	Estimated Power
Dominant Shoulder ER Strength	0.41	0.05	99%
Dominant Shoulder ER:IR Strength Ratio	0.20	0.05	91%
Normalized Dominant Shoulder ER Strength using %ND Strength Method[148]	0.22	0.05	95%

[a] The power analyses for Aim 2 were conducted using isometric shoulder strength data from a pilot study.
[b] Effect size was calculated to examine the expected difference between baseline and follow up measures using isometric shoulder strength data collected in a pilot study.

CHAPTER 4

SPORT SPECIALIZATION INCREASES UPPER EXTREMITY INJURY RISK IN YOUTH BASEBALL PLAYERS: A PROSPECTIVE COHORT STUDY

4.1 Abstract

Introduction: Despite rising awareness of the risks associated with year-round sports specialization, athletes continue to specialize at increasing rates across the U.S. The effects of sport specialization on the development of upper extremity (UE) injuries in baseball players have not been previously studied in youth populations.

Objective: The purposes of this study were to 1) establish UE injury incidence, and 2) examine the association of sport specialization and specialty training as a pitcher on UE injury rates in a cohort of youth athletes.

Methods: Youth baseball players (9-12 years old) were examined and then followed for approximately 6 months via coach/parent surveys. Athletic exposure (AE) and presence of UE injury was tracked per player. All athletes who reported injuries were re-examined by a licensed physical therapist. Athletes were classified as specialized or multi-sport using 2 methods: self-classification and research-based classification, however research-based results were used for data analysis. Chi square analyses were used to compare the frequency of UE injuries based on position group (pitchers vs. position players only), sports specialization status and participation in additional specialty training. Odds ratios, absolute, and absolute risk differences with 95% confidence intervals (CI) were calculated between groups.

Results: Uninjured male baseball players (n=159) were prospectively followed for an average of 6.7±1.5 months in this study. The UE injury incidence rate was 16.3/1000 AEs (95% CI=9.3, 23.3). The majority of athletes (83.0%) were classified as specialized in this cohort. Specialized athletes demonstrated a 15.9% increase in absolute risk for developing an UE injury when compared to multi-sport counterparts (*P*=0.03).

Conclusion: Sport specialization impacts an athlete's UE injury risk during youth baseball. USA Baseball's pitch count limitations were designed to decrease overuse injuries at the shoulder and elbow by requiring more athletes to pitch. This may have inadvertently had the opposite effect by increasing the rate of specialty training outside of competition.

Clinical Relevance: Participation in specialty training as a pitcher may influence the development of UE injuries in youth populations. Youth pitchers who took pitching lessons demonstrated a significant increase in absolute injury risk, which may be related to increased athletic exposure.

Keywords: youth baseball; risk factors; early sports specialization; early position specialization

4.2 Introduction

Baseball is a popular sport to play in the United States, with approximately 13-17 million athletes under the age of 18 participating at the club and high school levels.[4,31,51,143] The incidence of baseball-related overuse injuries is comparatively low in adolescent players (13-18 years old) with 1.3 – 4.0 injuries per 1,000 athletic exposures recorded.[31,137] It is unknown in youth baseball players (9-12 years old) as there is a significant lack of epidemiologic data in this population. The majority of baseball-related overuse injuries are reported in the upper extremity (UE), specifically at the shoulder and elbow, however little is known about the etiology and development of these injuries at the youth level.[31,137]

One potential explanation for the lack of epidemiologic data may be related to difficulties in injury surveillance, particularly in the younger age groups.[43,75] Unlike the collegiate and professional ranks, who employ athletic trainers to record and treat their injuries, youth and adolescent injuries are inconsistently reported, and often treated, by the athletes' parents and coaches.[43,113] The burden of identifying and recording injuries is much greater at this level as the majority of youth players participate on multiple teams, and in some cases multiple sports, throughout the year.[75]

Despite evidence suggesting that sport specialization may be related to the development of overuse injuries in youth and adolescent athletes, its prevalence continues to increase in the U.S.[72,107] Prior research has defined sport specialization based on a battery of criteria including year-round training in a single sport (>8 months/year), identification of a primary sport over additional sports and the cessation of additional sports to focus on a primary sport.[8,71,72,84] Despite established definitions in the literature, less is understood about the public perception of sports specialization with parents and coaches.[71,72,84,107,108] The effects of sport specialization on UE injury risk has not been previously established in the baseball literature. Other risk factors, such as excessive pitch counts, varied pitch types and faulty throwing mechanics, have been linked to the development of shoulder and elbow pain in youth throwers using self-report and survey data.[12,71,72,90,91,116,162] The USA Baseball Medical & Safety Advisory Committee used this research to establish age-appropriate guidelines for pitch counts, pitch types, throwing mechanics and most recently a long term athlete development model released in 2017.[12,19,90,91,109,136,140,148,154,155] The effectiveness of these recommendations on the reduction of baseball-related overuse injuries is unknown at this time.

The paucity of data describing UE injury incidence in youth baseball players poses a significant knowledge gap in the literature as the extent of the problem has not been accurately established in this population. Additional research is also needed to better understand the impact of sport specialization on shoulder and elbow injury risk in youth baseball players. The purposes of this study were to 1) establish UE injury incidence in a cohort of 9-12 year old male baseball players, and 2) examine the effects of sport specialization on the development of UE injuries in a cohort of 9-12 year old male baseball players.

4.3 Methods

4.3.a Study Population

This is a prospective cohort study of competitive male youth baseball players (9-12 years old) recruited in the spring of 2016. Two hundred and sixty one players were recruited from local baseball clubs, baseball tournaments and little leagues in South

Carolina and invited to participate in this study. One hundred and fifty nine athletes consented to participate. Asymptomatic competitive youth baseball players were followed for a 6-month period after baseline examination by a research team of licensed physical therapists. All players were male, between the ages of 9-12 years and participating in all baseball activities without restriction at the time of baseline examination. Pitchers and position players were recruited for this study, however youth teams are predominantly comprised of pitchers (Table 4.1). Position players were identified as any athlete who did not report pitching for an organized baseball team.

One hundred and two players were excluded from this study because they (1) reported any injuries that currently restricted their ability to participate in baseball activities, (2) reported a shoulder or elbow injury that required medical attention during the 3 months prior to initial examination or (3) did not respond the required number of times during the follow up period (3 times throughout the study with each response being <2 months apart). The University of South Carolina's Institutional Review Board (IRB) approved this study. Parental consent and athlete assent were obtained for each participant enrolled.

4.3.b Data Collection

At the time of enrollment (Spring 2016), each participant completed a study questionnaire using the RedCap online survey system prior to initial examination and throughout the 6-month follow up period. Participants were then contacted twice a month using online survey methods followed by phone and in-person interviews for improved response rates.

All participants completed a baseline online study questionnaire with the help of a parent or team coach. The initial questionnaire surveyed baseline characteristics, current sports participation, baseball-specific playing history and training history. Participants were asked to self-classify as either specialized or multi-sport athletes at the time of study enrollment (Figure 4.1). The research team then re-classified each participant as specialized or multi-sport, using previously stated research criteria (See Appendix A).[8,71,72] Follow up questionnaires surveyed baseball-related athletic exposure (i.e. team practice and game counts) first by team and then confirmed through individual report over the course of 6 months. Any shoulder or elbow impairments including pain, injury, tightness or weakness reported during that time were also recorded. Any player that reported a baseball-related shoulder or elbow impairment via survey was contacted and then physically examined by the lead researcher, a licensed physical therapist, to confirm the presence of injury. Acute trauma such as acute fractures, lacerations and abrasions were not included in this study.

Injuries were defined as any shoulder or elbow impairment that resulted in either: 1) an athlete missing ≥1 practice(s) or game(s), or 2) an athlete experiencing a reduction in their performance (i.e. decreased ball control or velocity) or change in position (i.e. moving from pitcher to 1st base) related to the UE complaint.[43,75,113,137] Following the physical examination, athletes who required additional medical care were referred to a board certified, fellowship-trained, sports medicine physician for continued evaluation.

4.3.c Statistical Analysis

Incidence rates were calculated per 1,000 athletic exposures for all UE injuries. Rate ratios (RR) and 95% confidence intervals were then calculated to determine injury rates in pitchers and position players only. Frequency counts were also calculated for each categorical variable. Chi square analyses were used to compare the frequency of all shoulder and elbow injuries between the following groups: sports specialization status, position played and participation in specialty training outside of team-sanctioned practices or games. Odds ratios (OR), absolute risk (AR) and absolute risk difference (ARD) with 95% confidence intervals (CI) were then respectively calculated for each of these groups. Absolute risk difference was determined by subtracting the AR of the exposed group (athletes who demonstrated the risk factor) from the AR of the unexposed group (athletes who did not demonstrate the risk factor). Statistical significance was set a priori at α=0.05. All statistical analyses were performed using SPSS Statistics 22.0 (SPSS Inc., Chicago, IL, USA) software.

4.4 Results

4.4.a Injury Incidence

The UE injury incidence rate in a cohort of healthy 9-12 year old male baseball players was 16.3/1000 AEs (95% CI = 9.3, 23.3). Twenty-one injuries were reported during the 6-month follow up period, 14 in pitchers (13.2%) and 7 in position players (13.2%). Pitchers represented 66.7% (n = 106) of the cohort and demonstrated an UE incidence rate of 16.6/1000 AEs (95% CI 7.9, 25.3) while position players represented 33.3% (n = 53) of the cohort and demonstrated 15.8/1000 AEs (95% CI 4.1, 27.5). The difference in incidence rates was not significant (RR = 1.1, 95% CI = 0.4, 2.6; *P* = 0.91). The proportion of UE injuries was highest at the shoulder (61.9%, n = 13), followed by the elbow (38.1%, n = 8) in youth baseball players. This pattern was consistent in pitchers (shoulder: 66.7%, n = 10; elbow: 33.3%, n = 5) while position players demonstrated an equal injury distribution across both sites (shoulder: 50.0%, n = 3; elbow: 50.0%, n = 3). Despite these observations, location of UE injury was not significantly different between pitchers and position players (*P* = 0.48). Of the 21 athletes who sustained injuries in the study, only 1 reported a history of overuse UE injury prior to the onset of symptoms.

4.4.b Early Sport Specialization

At the start of the study, participants were asked to self-classify as either specialized or multi-sport athletes based on their or their parents' perceptions of sport specialization in youth baseball. Thirty-one percent of youth athletes (n = 49) self-classified as specialized in baseball while the remaining 69.0% (n = 110) identified as multi-sport athletes (Figure 4.1). The research team then re-classified each participant as specialized or multi-sport, using research-based criteria found in the literature.[8,71,72] Based on these criteria, 83.0% of the cohort (n = 132) qualified as specialized athletes while only 17.0% (n = 27) were classified as true multi-sport athletes (Figure 4.1). The study results showed that a significant number of youth baseball players were misclassified as multi-sport athletes yet participated and competed as specialized athletes (57.9%, n = 92; *P* = 0.001). The research-based methods were used for athlete classification the remainder of the statistical analyses. Youth baseball players that competed as specialized athletes were at a significantly greater risk for developing a shoulder or elbow injury when compared to their multi-sport counterparts (OR = 1.2, 95% CI 1.1, 1.3; *P* = 0.03) (Table 4.1).

4.4.c Early Position Specialization

The majority of youth baseball players in this cohort participated in some type of additional sport-related training (84.9%, n = 135). One hundred and eleven players took formal hitting lessons (69.8%), 72 took formal pitching lessons (67.9%) and 36 participated in generalized strength and conditioning programs (22.6%) (Table 4.1). Youth baseball players who participated in formal hitting lessons demonstrated no differences in injury frequency compared to players who did not (P = 0.86) (Table 4.1). Players who participated in formal pitching lessons did show an increased frequency of shoulder and elbow injuries compared to those who did not (P = 0.04) (Table 4.1). Youth athletes who demonstrated this early position specialization as a pitcher were found to be 2.8 times as likely (95% CI 1.1, 7.3; P = 0.04) to experience a shoulder or elbow injury when compared to athletes who did not specialize early as a pitcher (Table 4.1). Participation in generalized strength and conditioning programs did not impact injury frequencies in youth baseball players when compared to the athletes who participated solely in baseball-specific training (P = 0.60) (Table 4.1).

4.5 Discussion

The most important result of our study shows that youth baseball players who specialize in baseball displayed greater shoulder and elbow injury risk compared to those who did not specialize. Interestingly, youth players who also participated in additional specialty training, particularly as a pitcher, were at the greatest risk for sustaining a shoulder or elbow injury in this cohort. This is concerning given that two-thirds of youth baseball players identified as pitchers and reported participating as position players when not pitching. These findings suggest that not only is specialization an issue but that physical overtraining may also contribute to the observed disparities in injury rates.

4.5.a Injury Incidence

During the 6-month study period, youth baseball players demonstrated an UE injury rate of 16.3/1000 AEs, markedly higher than the injury rates previously reported in high school (4.0/1000 AEs) and collegiate players (5.83/1000 AEs).[36,137] The higher injury rate may be, in part, due to differences in the injury definitions between studies. Previous research examining injury profiles in youth baseball players relied on self-report measures from survey data to establish risk factors associated with UE pain in this population.[90,91,116,162] This research indicated that nearly 50% of youth athletes reported experiencing shoulder or elbow pain during the course of a baseball season, however a licensed medical professional did not physically confirm these reports as was done in our study.[90,91,116,162] Prospectively examining UE injury profiles has allowed us to build on the knowledge gained from previous studies and generate a more complete picture of UE injury development in youth baseball.

In contrast to previous studies on high school, collegiate and professional pitchers, the majority of youth baseball players pitch in some capacity and play additional field positions when not pitching.[31,36,137] Based on discussions with Little League and competitive travel team coaches, the majority of youth baseball teams that participated in this study included a mean of 12 players per roster with 8 or more competing as pitchers throughout the season. This is likely a result of the USA Baseball pitch count limitations, which require teams to distribute the physical demands of pitching across multiple players in an attempt to limit overuse.[32] Based on data collected from team coaches, teams typically play 2-4 tournaments per month with 4-5 games per tournament during competitive seasons. Each youth baseball game lasts 4-6 innings with pitch counts that may exceed 100 pitches per game.[86] Depending on the number of batters faced and the number of innings played, a minimum of 6 pitchers is required to participate in 1 youth baseball tournament. The pitch count recommendations stem from previous research that linked excessive pitch counts and improper throwing mechanics to shoulder and elbow pain in a cohort of youth baseball pitchers.[53,90,91]

This study was the first to examine UE injuries in a cohort of youth baseball players, irrespective of position. While pitchers sustained the majority of the injuries reported, injury proportions were equal between positions, as pitchers also comprised the majority of the sample. We found no differences in absolute risk for developing a shoulder and elbow injury in youth pitchers when compared to their position player counterparts (Table 4.1). These findings were in contrast to previous research performed in the high school, collegiate and professional ranks which indicated that pitchers were at a significantly higher risk for sustaining an UE injury when compared to position players.[36,123,137]

4.5.b Early Sport Specialization

Specialization in a single sport, prior to the onset of adolescence, has been repeatedly identified as a risk factor for injury across multiple sports.[39,71,72,84,99,107,108] Current research also suggests early sport specialization does not correlate with an athlete's long-term success in sport and that early diversification may be more beneficial to their physical development.[84] USA Baseball recently released a Long Term Athlete Development Model which advises athletes to avoid specializing in a single sport prior to

14 years of age.[109] Despite these widespread recommendations, youth athletes continue to specialize in a single sport at alarming rates. Based on well-established research criteria, 83% of the youth baseball players in this study were classified as specialized athletes (Table 4.1).[71,72] Our results showed that sport specialization in baseball significantly increased an athlete's absolute risk for sustaining a shoulder or elbow injury when compared to sport diversification (Table 4.1). These findings are consistent with previous research and support the recommendations put forth by USA Baseball in their Long Term Athlete Development Model.[72,99,109]

One potential reason for the continuation of sport specialization in youth athletes, despite the acknowledged risks associated with it, is a lack of understanding of its definition. Sport specialization has been defined in the literature as 'intense training for >8 months per year in a single sport to the exclusion of other sports.'[71,84] At the start of our study, athletes, typically with the help of parents and coaches, were asked to self-classify as either specialized or multi-sport athletes. Approximately 70% of the players classified themselves as multi-sport athletes based on their own perceptions (Figure 4.1). Based on previous research, 83% of this youth cohort were classified and competed as specialized athletes suggesting a significant discrepancy in athlete (and parental) perception of what constituted sport specialization (Figure 4.1). When asked to expand upon their views on sport specialization, parents and coaches stated that they encouraged their athletes to participate in multiple sports in addition to competing in year-round baseball activities. These attitudes seem to contribute to overscheduling with little time for rest and recovery and may prove detrimental to an athlete's health and long-term success in sport.[84]

4.5.c Early Position Specialization

The effects of early specialty training, or position specialization, were examined in this study. Athletes who took formal hitting lessons or any variation of baseball-specific training, prior to the onset of adolescence, did not demonstrate an increased risk for injury when compared to those who did not (Table 4.1). Athletes who participated in formal pitching lessons however, did demonstrate a greater absolute risk for sustaining a shoulder or elbow injury in baseball when compared to those who did not (Table 4.1). With the advent of age-based pitch count restrictions, youth teams are required to carry more pitchers than their high school counterparts. In this cohort, the majority of youth pitchers sought out formal pitching lessons (67.9%) in an effort to improve athletic performance. Specialty training as a pitcher, in addition to pitching in practices and games, may result in increased physical loads being placed across an athlete's shoulder and elbow joints. Participating in formal pitching lessons, prior to the onset of adolescence, may derail the original purpose of age-based pitch count restrictions, which was to reduce physical loads across a growing athlete's body. Also, per USA Baseball and their Long Term Athlete Development Model, specialty training may not be as beneficial as generalized physical training for youth athletes at this stage of physical development.[71,84,107,108] Despite age-specific recommendations that emphasize the importance of physical literacy and functional skill acquisition, remarkably few youth baseball players took generalized strength and conditioning lessons in this cohort (22.6%). Future authors should examine the impact of participation in generalized physical training programs over specialty training programs on injury risk and performance in youth athletes.

4.5.d Strengths

To our knowledge, this is the first study to report UE injury incidence in a cohort of youth baseball players. This research is novel with respect to both the study population and its prospective design. Less than 10% of all injury risk and prevention data has been collected in athletes <18 years old, with even less data describing youth athletes (9-12 years old).[98] Despite the fact that youth and adolescent athletes comprise the majority of the population competing in sports, they continue to be significantly understudied.[85] The prospective design allowed UE injury incidence in a cohort of youth baseball players to be established. In addition, the study was strengthened because there was confirmation of all injuries reported in this study via physical examination as opposed to self-report measures. This study provides insight into the unique injury profiles and actual participation levels of youth baseball players compared to well-studied collegiate and professional baseball players.

4.5.e Limitations

Certain limitations should be noted while interpreting the results of this research. Previous epidemiological studies have typically included injury rates for all injuries across an athlete's body while this study reported injury rates solely at the shoulder and elbow.[31,43,124,137] This decision was based on previous data that shows the shoulder and elbow to be two of the most commonly injured body parts in competitive baseball players.[80,124,137] Additional limitations in this study include the obvious disparities in the number of youth pitchers versus position players reported as well as the number of specialized athletes versus multi-sport athletes reported in this study. While the groups were uneven for statistical analysis, the proportions for each position and participation level were representative of the population being studied. Lastly, to capture an adequately sized sample of youth baseball players, baseline evaluations required a 10-week period to complete throughout the competitive season. Athletes were then tracked for 6 months following individual baseline evaluations. This resulted in varied baseball participation rates among youth athletes that were likely impacted by competition level (i.e. little league baseball vs. tournament team baseball) and participation in additional sport seasons (i.e. football season, basketball season). The variability in baseball participation over a 6-month calendar period may have influenced the consistency of our athletic exposure data however was representative of youth athlete participation rates in baseball.

4.6 Conclusion

Youth baseball players demonstrated higher UE injury incidence rates than previously reported in adolescent baseball populations. Sport and position specialization, prior to the onset of adolescence, increases an athlete's absolute risk for developing an UE injury during youth baseball. USA Baseball's age-based pitch count limitations were designed to decrease overuse injuries at the shoulder and elbow by requiring more athletes to pitch. This may have inadvertently had the opposite effect by increasing the rate of specialty training outside of competition.

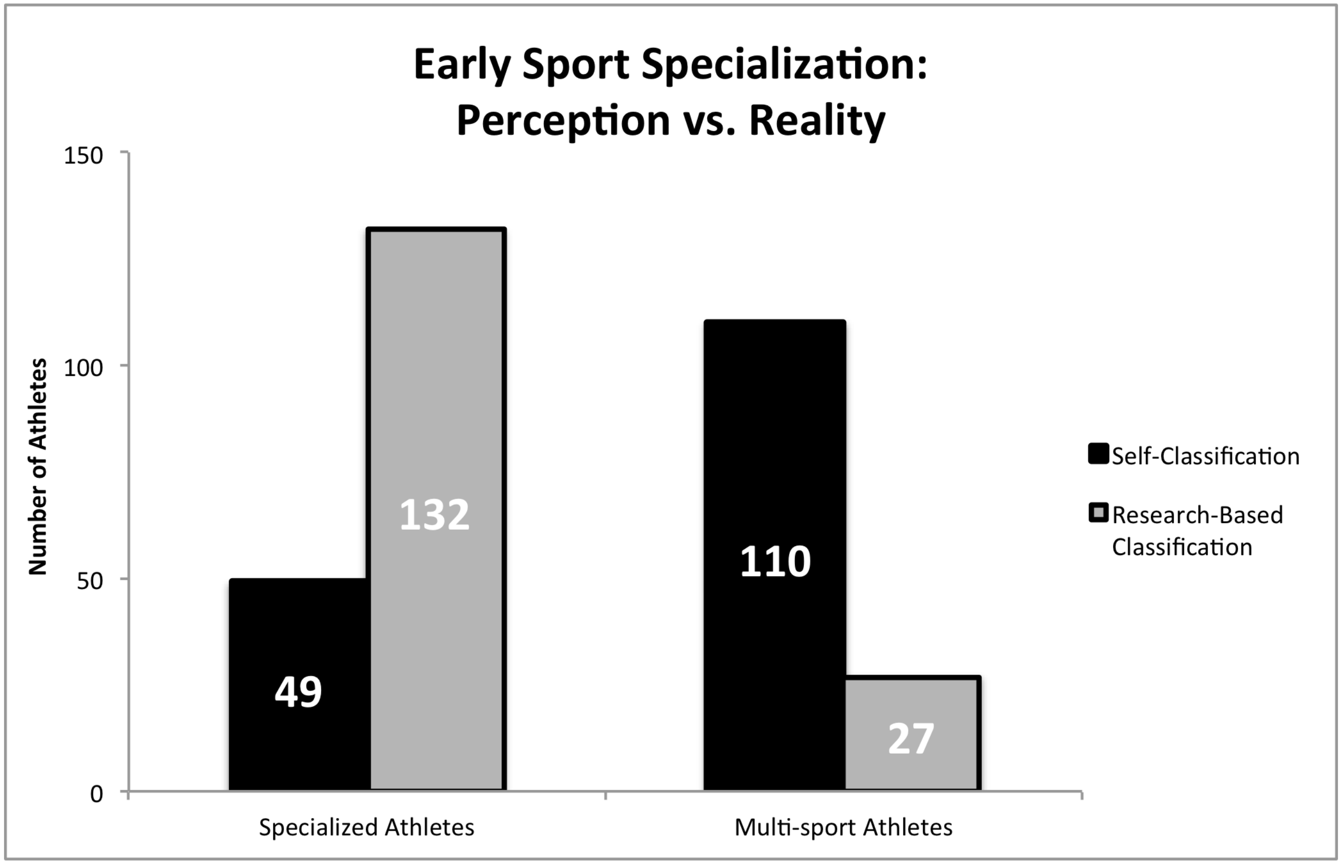

Figure 4.1 Sport Specialization – Perception vs. Reality

Table 4.1. Analysis of Risk Factors for Upper Extremity Injuries

Variable	*n* *(% of total cohort)*	*Odds Ratio (95% CI)*	*Absolute Risk (%)*	*Absolute Risk Difference[b] (%) (95% CI)*	*P* value
Position					
- Pitchers	106 (66.7)	1.0 (0.4, 2.7)	13.2	0.0	1.00
Position Players Only	53 (33.3)	Referent	13.2	(-11.1, 11.1)	
Sport Specialization					
- Specialized Athlete	132 (83.0)	1.2 (1.1, 1.3)	15.9	15.9	**0.03***
Multi-Sport Athlete	27 (17.0)	Referent	0.0	(9.7, 22.1)	
Position-Specific Training					
- Hitting Lessons	111 (69.8)	1.1 (0.4, 3.0)	13.5	1.0	0.86
No Hitting Lessons	48 (30.2)	Referent	12.5	(-10.3, 12.2)	
- Pitching Lessons	72 (45.3)	2.8 (1.1, 7.3)	19.4	11.3	**0.04***
No Pitching Lessons	87 (54.7)	Referent	8.1	(6.2, 22.2)	
- Baseball-Specific Training[a]	118 (74.2)	2.3 (0.6, 8.2)	15.2	7.9	0.20
No Baseball-Specific Training[a]	41 (25.8)	Referent	7.3	(-2.3, 18.2)	
General Physical Training					
- Strength & Conditioning Lessons	36 (22.6)	1.4 (0.5, 4.0)	16.7	4.5	0.49
No Strength & Conditioning Lessons	123 (77.4)	Referent	13.9	(-9.0, 17.9)	

**Indicates a statistically significant difference (P < 0.05).*

[a] Baseball-Specific Training was comprised of players who took only hitting lessons (n = 46), only pitching lessons (n = 7) or a combination of both (n = 65).

[b] Absolute Risk Difference = Absolute Risk of Non-Exposed Group – Absolute Risk of Exposed Group.

CHAPTER 5

NORMALIZATION METHODS IN ISOMETRIC SHOULDER STRENGTH IN YOUTH BASEBALL PLAYERS: A COMPARISON ACROSS 5 METHODS

5.1 Abstract

Introduction: The measurement of shoulder muscle strength is an important component in the physical assessment of overhead athletes. Although several measures have been described, isometric testing using hand held dynamometry (HHD) has proven to be a reliable, low cost and portable method in this population. The use of this procedure in youth athletes (ages 9-12 years) is challenging because of the wide variations observed in strength testing performance. These variations may result from substantive differences in anthropometric characteristics such as height and weight. Considering this, 'normalized' strength measures that account for an individual's current body size may be of great use in understanding the relationship between shoulder strength and athletic performance in youth baseball players.

Objective: The purposes of this study were to 1) compare the measurement properties of 5 potential methods for normalizing isometric shoulder muscle strength and 2) examine the relationship between normalized isometric shoulder muscle strength and ball velocity in a cohort of 9-12 year old male baseball players.

Methods: One hundred and fifty nine male youth baseball players (mean age 11.1±1.1 years) volunteered for this study. Baseline and follow up height, weight and ulnar length measurements were assessed followed by isometric strength in both the dominant and non-dominant shoulders. Ball velocity was assessed as a measure of throwing performance. Intraclass correlation coefficients (ICC), standard errors of measurement (SEM) and minimal detectable change (MDC) were calculated for all baseline and follow-up strength measures. Repeated measures analyses of variance (ANOVA) were conducted to compare changes in isometric shoulder strength at 2 time points after normalizing to 5 separate measures of body size. Linear regression models were used to examine the relationships between normalized isometric shoulder torque measures and ball velocity. Statistical significance was set a priori at $\alpha=0.05$.

Results: Torque, defined as the measure of shoulder strength divided by the corresponding ulnar length, was the only method that demonstrated excellent reliability ($ICC_{2,1}$ 0.98-0.99) and detected significant changes between shoulder strength in each of the 4 measures tested (SEM 0.39-0.69 Nm). Modest but significant correlations were observed between scaption torque and ball velocity ($r^2 = 0.27$, P < 0.001) and external rotation (ER) torque at 0°and ball velocity ($r^2 = 0.23$, $P < 0.001$).

Conclusion: The normalization method that demonstrated the most consistent measurement properties for the assessment of isometric shoulder strength in a youth baseball player was torque. Ulnar length is the most stable and reliable anthropometric measure evaluated in this study. Once normalized, isometric shoulder scaption strength was the most significant predictor of ball velocity, followed by ER strength at 0° in 9-12 year old baseball players.

Keywords: torque; youth; baseball; normalization; ball velocity

5.2 Introduction

Upper extremity muscle strength is an important component in the assessment of athletic performance and injury prevention in baseball players.[17,28,44,50,52,61,97,105,148,156,160] Strength is defined as the amount of force a muscle can maximally produce during a single repetition.[67,68,70] Clinicians and researchers routinely use a battery of strength measures in performance assessments, injury diagnostics and return to sport decisions following injury.[17,33,61,148] While upper extremity strength measures have been widely reported at the collegiate and professional levels, little to no evidence is available describing these measures at the youth and adolescent levels.[17,28,33,44,50,61,97,105,148,156] Establishing an objective and reliable method for evaluating strength is imperative in understanding shoulder function and injury risk in youth baseball players.[33,148]

A variety of methods, including isokinetic, isometric and functional testing, have been used to measure shoulder strength in athletic populations.[17,28,44,61,97,148,160] While isokinetic testing is considered the gold standard in strength assessment, the high equipment costs and lack of portability make it impractical for use outside of laboratory settings.[33,52,142] Isometric testing using hand held dynamometry (HHD) has proven to be a reliable alternative to isokinetics in assessing strength at the shoulder.[17,33,142,148] Hand held dynamometry is low cost, portable and easy to use however it does have acknowledged limitations including investigator strength, lack of stabilization and inconsistencies in testing procedures.[33,52]

The majority of isometric strength testing has been conducted in collegiate and professional baseball players with few studies examining shoulder strength in younger players.[17,44,61,97,105,148] Despite acknowledging that anthropometric measurements, such as height and weight, influence the body's ability to produce force and thereby muscle strength, normalization methods accounting for body size are inconsistently reported in the literature.[44,67,68,97,105] The evaluation of isometric strength in youth and adolescent athletes is inherently different from that of collegiate and professional athletes.[67,68,92] Height, weight and neuromuscular control can fluctuate frequently in physically developing populations with the potential to rapidly change over short periods of time. Performance assessments that rely solely upon absolute measures, without normalization, may lack the ability to discern changes in muscle strength from changes in body size in youth populations.[67,68,70] Accounting for these alterations in growth and development through normalization is critical to accurately assessing muscle function and injury risk in young athletes.[67,68,92]

There is a notable gap in the literature surrounding the evaluation and normalization of shoulder strength in youth baseball players. Research suggests normalization methods, which include body mass, body mass index (BMI), height, torque and percent of non-dominant shoulder strength described by Trakis[148] may be potential methods for assessing muscle strength and changes in muscle strength over time in this population.[63,67,68] The purposes of this study were to 1) compare the measurement properties of 5 potential methods for normalizing isometric shoulder strength in a cohort of 9-12 year old male baseball players and 2) examine the relationship between normalized isometric shoulder strength and ball velocity in a cohort of 9-12 year old male baseball players.

5.3 Methods

5.3.a Study Population

One hundred and fifty nine competitive male youth baseball players with a mean age of 11.1 ± 1.1 years volunteered to participate in this study (Table 5.1). All players in this study were recruited from local baseball clubs, baseball tournaments and little leagues in the Upstate Region of South Carolina. All players were male, between the ages of 9-12 years and uninjured at the time of initial examination. Players were excluded from the study if they (1) reported any injuries that currently restricted their ability to participate in baseball activities or (2) reported a shoulder or elbow injury that required medical attention during the 3 months prior to initial examination. The University of South Carolina's Institutional Review Board (IRB) approved this study. Parental consent and athlete assent were obtained for each participant enrolled.

5.3.b Instruments

Height, weight and ulnar length were measured with using a portable stadiometer, digital weight scale and body tape measure, respectively. Athletes were asked to remove their footwear for anthropometric measurements. Height and ulnar length were recorded to the nearest 0.5 centimeter (cm) while weight was recorded to the nearest 0.1 kilogram (kg). Isometric shoulder strength was measured using a Lafayette Manual Muscle Tester hand-held dynamometer (Lafayette Instrument Company, Lafayette, IN, USA). All isometric strength measurements were performed by the lead researcher who demonstrated excellent intra-rater reliability prior to initial data collection ($ICC_{2,1}$ = 0.94-0.99). Ball velocity was assessed using a Stalker Sport Radar Gun (Stalker Radar, Richardson, TX, USA).

5.3.c Procedures

At the time of study enrollment, baseline height, weight and ulnar length measurements were assessed for each participant followed by isometric shoulder strength in both the dominant and non-dominant arms (Table 5.2). Two values of each strength measure were recorded per arm and averaged for statistical analysis. Isometric shoulder strength was assessed bilaterally using a Lafayette Manual Muscle Tester hand-held dynamometer and methods previously reported in the literature.[17] Isometric shoulder strength measures included abduction in the scapular plane (scaption) at 90°, external rotation (ER) at 0°, ER at 90° and internal rotation (IR) at 90° for the dominant and non-dominant arms (Table 5.2). Make tests were used for each isometric strength measure based on higher reliability when compared to break tests in hand-held dynamometers.[146] Scaption and ER at 0° forces were measured in the seated position (Figure 5.1). Scaption was measured with the dynamometer placed 5 cm distal to the cubital fossa while ER at 0° was measured with the dynamometer placed on the dorsal aspect of the forearm, 2 cm proximal to ulnar styloid process (Figure 5.2). External rotation at 90° and IR at 90° was measured with the shoulder in 90° of abduction, 90° of ER and 90° of elbow flexion (Figure 5.2). The dynamometer was placed on the dorsal aspect of the forearm, 2 cm proximal to ulnar styloid process. Internal rotation at 90° was assessed in a similar fashion to ER at 90°, however the shoulder was in a state of neutral rotation and the dynamometer was placed on the volar aspect of the forearm (Figure 5.2). Each participant was asked to provide maximal effort throughout each trial during examination.[17,46] Isometric shoulder strength was then normalized prior to statistical analysis using 5 separate methods: body mass, body mass index (BMI), height, torque and the Trakis Method (Table 5.3).[148]

Height, weight, ulnar length and isometric shoulder strength measurements were re-assessed in a subset of participants (n = 58) to examine changes in body size and strength over the 6-month period (Table 5.2). Isometric shoulder strength was again normalized for statistical analysis using the 5 previously stated methods: body mass, BMI, height, torque and the Trakis Method (Table 5.3).[148]

Throwing performance was assessed using ball velocity during an overhead throw. This measure was assessed in a subset of participants (n = 80). Following a warm up period during team practice, participants were asked to throw 3 balls from a distance of 46 feet on flat ground to a specified target. A Stalker Sport Radar Gun (Stalker Radar, Richardson, TX, USA) was used to record the velocity of each throw in miles per hour (mph). The 3 throws were recorded and averaged for statistical analysis.

5.3.d Statistical Analysis

Means and standard deviations (SD) were calculated across all participants for the dependent variables: height, weight, BMI and normalized shoulder strength measures. Reliability was assessed for all baseline and follow-up strength measures using intraclass correlation coefficients (ICC) with corresponding 95% confidence intervals (CI).[122] Standard errors of measurement (SEM) were also calculated to determine the absolute reliability of each strength measure using the largest SD in the formula $\mathrm{SD} \times \sqrt{1-\mathrm{ICC}}$.[122] Individual SEMs were then used to calculate corresponding minimal detectable change (MDC) values for each of the normalized strength measures using the formula $\mathrm{SEM} \times 1.96 \times \sqrt{2}$.[122] Repeated measures analyses of variance (ANOVA) were conducted to compare changes in isometric shoulder strength at 2 time points (baseline and follow-up) after co-varying for physical growth and body size. Effect sizes were calculated to identify the magnitude of change detected between the 2 time points for each of the normalized strength measures. Linear regression models were used to examine the relationships between the normalized isometric shoulder strength measures and ball velocity in youth baseball players. The method with the most consistent measurement properties for normalizing isometric shoulder strength in youth baseball players was determined based on each measure's test-retest reliability, ability to detect changes over time and strength of association with ball velocity. Statistical significance was set a priori at $\alpha=0.05$. All statistical analyses were performed using SPSS Statistics 21.0 (SPSS Inc., Chicago, IL, USA) software.

5.4 Results

5.4.a Normalization Methods Reliability

Baseline anthropometric characteristics of youth baseball players are reported in Table 5.1. Reliability data for the torque normalization method are reported in Table 5.4. The intra-rater reliability for the remaining 4 normalization methods were: body mass $ICC_{2,1}$ 0.97-0.98, BMI $ICC_{2,1}$ 0.95-0.98, height $ICC_{2,1}$ 0.94-0.98 and Trakis $ICC_{2,1}$ 0.80-0.98. Their respective SEM values were: body mass 0.46-0.63%, BMI 0.95-1.16 kg/m^2, height 0.12-0.28 kg/m and Trakis 4.15-15.00% (Figure 5.3). High inter-participant variability was apparent in each of the strength normalization methods, with the exception of torque, which suggests a lack of stability in these measures in test-retest situations (Figure 5.3). Torque was the only method to demonstrate good-to-excellent reliability and detect significant changes in shoulder strength over time in each of the 4 measures tested based on corresponding MDC_{95} values (Table 5.4).

5.4.b Shoulder Torque and Ball Velocity

The relationship between normalized isometric shoulder torque and ball velocity was examined using stepwise linear regression models with forward selection to determine the impact of each measure. Four normalized shoulder strength measures were entered into the model. Scaption torque demonstrated a high correlation with ball velocity and was entered into the model first followed by ER at 0° torque, ER at 90° torque and IR at 90° torque. A significant relationship was observed between scaption torque and ball velocity (r^2 = 0.27, P < 0.001) (Figure 5.4). The remaining measures demonstrated non-significant relationships with ball velocity when scaption was entered first into the model (ER at 0° torque r^2 = 0.27, P = 0.59; ER at 90° torque r^2 = 0.28, P = 0.69). Internal rotation torque was completely removed from the model. A second model was run with ER at 0° torque entered first followed by the 3 remaining measures. Significant relationships were observed between ER at 0° torque and ball velocity (r^2 = 0.23, P < 0.001) and scaption torque and ball velocity (r^2 = 0.23, P = 0.04) in this model (Figure 5.4). The remaining measures demonstrated non-significant relationships with ball velocity when ER at 0° torque was entered first into the model (IR at 90° torque r^2 = 0.28, P = 0.30). External rotation torque at 90° was completely removed from the model. Tests for collinearity indicated that a high level of collinearity was present between scaption torque and ER torque at 0° measures (*Eigenvalue* = 1.96) in the regression models. Based on these findings, scaption torque alone predicts 27% of ball velocity in youth baseball players while ER torque at 0° predicts 23% of ball velocity when measured in these athletes.

5.5 Discussion

This study investigated five distinct methods for normalizing isometric shoulder strength to determine which had the best measurement properties for youth baseball players. The torque method demonstrated excellent intra-rater reliability, with the lowest reported SEM and MDC values of any method examined. Once normalized, dominant shoulder scaption torque was the most predictive measure with respect to ball velocity, followed by dominant shoulder ER torque at 0°. Dominant shoulder scaption torque alone predicted 27% of the variation in ball velocity in a cohort of youth baseball players. Results also indicated that dominant shoulder ER torque at 0° was strong measure and could be used independently of dominant shoulder scaption torque to predict 23% of the variation in ball velocity in this cohort.

5.5.a Normalization Method Types

Few original research studies have employed normalization methods when examining muscle strength measures and none have compared findings to determine the most appropriate method based on a specific population.[132,148] Previous literature impresses the importance of normalizing strength measures for accurate comparison across multiple time points, particularly in longitudinal and repeated measures study designs.[67,68] In the absence of normalization, any observed changes in muscle strength may be misinterpreted as simply functions of growth and physical development as opposed to definitive changes in the measures themselves.[67,68] A study by Trakis[148] using isometric testing and HHD referenced dominant shoulder strength measures to non-dominant shoulder strength measures as a means of normalizing muscle strength in adolescent baseball players. The theory was based on the concept of using non-dominant shoulder strength values as internal reference points for each athlete.[148] When the Trakis method[148] was applied in younger players, ages 9-12 years old, excessive inter-participant variability was noted both in single session measures and repeated measures over time. Neuromuscular control patterns in youth athletes are not as well developed as their adolescent and adult counterparts, which may impact their ability to reproduce consistent results with isometric muscle strength measures.[54,62,63,84]

Biomechanical studies have suggested the use of body mass and derivations of body mass, including BMI, as potential normalizing factors though few studies have formally tested those theories on youth and adolescent athlete populations.[70,132] Frequent fluctuations in body mass measures imply that, while the weight of a youth athlete certainly contributes to their ability to produce muscle force, is may not possess the stability required to accurately detect changes in muscle strength measures over time.[68,70] Height and torque, a derivation of height, appeared to be more stable choices for normalization factors as the measures only increase over time in youth athlete populations. When the normalization methods containing height and torque were compared, the limb-specific torque method outperformed the more generalized height method in test-retest reliability as well as internal consistency as evidenced by lower SEM and MDC values. These findings indicate that torque was the most consistent normalization method for assessing isometric muscle strength at the shoulder in youth baseball players.

5.5.b Shoulder Torque and Ball Velocity

Dominant shoulder scaption strength and ER strength at 0° have been previously linked to throwing performance and upper extremity injury risk in baseball players.[17,44,61,97,105,148] The majority of studies examining upper extremity strength as a factor for performance and injury risk were performed in collegiate and professional athletes.[44,50,97,105] Studies have found little conclusive evidence supporting the theory of a direct relationship between baseline shoulder muscle strength and ball velocity in throwers, however shoulder muscle weakness has been repeatedly linked to injury throughout the baseball literature.[17,28,97,105,133] Magnusson[97], Mullaney[105] and Byram[17] have all shown that pitchers demonstrated deficits in dominant shoulder scaption and ER muscle strength. While we did not examine the effects of normalized dominant shoulder scaption torque on injury risk in this study, our results do support the significance of measuring dominant shoulder scaption torque with regards to performance measures in competitive baseball players.

To our knowledge, this is the first study to show a positive association between normalized isometric shoulder torque and ball velocity, an acknowledged performance measure in youth baseball players.[89,90,116] Minimal data exists examining upper extremity muscle strength and injury risk in youth athletes. One study exists by Harada[61] compared a battery of shoulder muscle strength measures and injury risk in a cohort of Japanese youth baseball players. They found that injured athletes demonstrated greater dominant shoulder strength compared to uninjured athletes.[61] These findings suggest that the connection between shoulder strength and upper extremity injury risk may be different in youth athletes when compared to their collegiate and professional counterparts, however further studies are needed to better understand these relationships.[17,61,97,105]

5.5.c Limitations

Isometric muscle strength testing using hand held dynamometry has several clinical advantages such as low cost, portability and ease of use however it also has acknowledged limitations.[33,52] While extreme effort was expended to standardize all measurements and testing procedures including using a single investigator with excellent intra-rater reliability, no external stabilization methods were applied to the athletes during the assessments. This decision was based on feasibility and applicability in clinical settings however may have influenced our results.

Another potential limitation of this study was the collinearity between the isometric shoulder scaption torque and ER torque at 0° measures in this population. Our results indicate that either measure is predictive of ball velocity however further research is needed to determine what additional variables should be included in the model to best explain this performance measure in youth athletes. Overhead throwing is a complex motor skill that requires coordination and the proper sequencing of a series of linked movements that start in the lower extremities and ultimately culminate in ball release.[157] This statement supports our findings that isometric shoulder strength explains only a portion of the variability observed in ball velocity in young throwers.

Lastly, the high levels of inter-participant variability observed in isometric shoulder ER and IR torque at 90° may have negatively influenced the predictability of these measures in youth athletes. The variability may be attributable to age-appropriate deficits in neuromuscular control in the prone overhead position however further study is needed to better understand the role neuromuscular control plays in youth baseball throwing mechanics. Future studies should consider the use of isometric shoulder torque measures, not only in performance assessments of youth athletes, but in injury prevention programs as well. The relationship between upper extremity injury risk and isometric shoulder strength is not well understood in youth populations suggesting that further study is warranted.

5.6 Conclusion

The normalization method with the best measurement properties for assessing isometric shoulder strength in youth baseball players was torque. Ulnar length is the most stable and reliable anthropometric measure evaluated in this study. Once normalized, isometric shoulder scaption strength was the most significant predictor of ball velocity, followed by ER strength at 0° in 9-12 year old baseball players. Muscle strength assessments performed in 90° of shoulder abduction demonstrated high inter-subject variability and provided minimal information concerning the shoulder function and athletic performance of youth baseball players.

Table 5.1. Baseline Characteristics of Youth Baseball Players

	N	Mean	SD[a]
Age, years	159	11.1	1.1
Height, cm	159	146.8	8.3
Weight, kg	159	41.6	10.1
BMI[b], kg/m^2	159	19.1	3.4
Arm Dominance Right, %	137	86.2%	-

[a]SD, standard deviation.
[b]BMI, body mass index.

Table 5.2. Overview of Anthropometric & Isometric Shoulder Strength Measures

Type of Measure	Testing Equipment	Body Position	Arm Position	Examiner Position
Anthropometric				
1. Height	Stadiometer	Standing	-	Standing
2. Weight	Digital Scale		-	
3. Ulnar Length	Tape Measure	Supine	-	
Isometric Strength				
4. Scaption	Hand Held Dynamometer	Sitting	Shoulder Abducted 90° Horizontally Adducted 45° Rotation Neutral	Standing Anterior to Testing Arm
5. External Rotation at 0°			Shoulder Abducted 0° Elbow Flexed 90° Forearm Rotation Neutral	Standing Perpendicular to Dorsal Forearm
6. External Rotation at 90°		Prone	Shoulder Abducted 90° Externally Rotated 90° Elbow Flexed 90°	Standing Inferior to Testing Arm
7. Internal Rotation at 90°			Shoulder Abducted 90° Rotation Neutral Elbow Flexed 90°	Kneeling Inferior to Testing Arm

Table 5.3. Normalization Methods for Isometric Shoulder Strength

Method	Calculation
Body Mass (kg)	$= \frac{\text{Shoulder Strength Measure}}{\text{Body Mass}}$
BMI (kg/m^2)	$= \frac{\text{Shoulder Strength Measure}}{\text{BMI}}$
Height (m)	$= \frac{\text{Shoulder Strength Measure}}{\text{Height (m)}}$
Muscle torque (Nm)	$= \frac{\text{Shoulder Strength Measure (N)}}{\text{Ulnar Length (m)}}$
Percent Non-Dominant Strength Method (%)[148]	$= \frac{\text{(Dominant Shoulder Strength – Non-Dominant Shoulder Strength)}}{\text{(Non-Dominant Shoulder Strength)}}$ **x 100**

Table 5.4. Reliability of Normalized Dominant Isometric Shoulder Strength using Torque Method

	Mean	SD[a]	$ICC_{2,1}$ (95% CI)[b]	SEM[c]	MDC_{95}[d]	Effect Size[e]
Baseline Strength (n=159)						
- Scaption	17.9	5.2	0.99 (0.94, 0.99)	0.57	1.6	-
- External Rotation at 0°	15.2	4.1	0.99 (0.99, 1.00)	0.52	1.4	-
- External Rotation at 90°	11.9	3.0	0.98 (0.93, 0.99)	0.39	1.1	-
- Internal Rotation at 90°	16.3	4.0	0.99 (0.95, 0.99)	0.45	1.3	-
Follow-Up Strength (n=58)						
- Scaption	20.7	6.2	0.99 (0.98, 0.99)	0.69	1.9	-
- External Rotation at 0°	19.0	5.5	0.99 (0.97, 0.99)	0.54	1.5	-
- External Rotation at 90°	14.1	3.3	0.98 (0.98, 0.99)	0.46	1.3	-
- Internal Rotation at 90°	19.0	4.5	0.99 (0.96, 0.99)	0.55	1.5	-
Strength Change over Time (n=58)						
- Scaption	2.8	3.4	-	-	-	0.41
- External Rotation at 0°	3.8	3.6	-	-	-	0.54
- External Rotation at 90°	2.2	2.2	-	-	-	0.51
- Internal Rotation at 90°	2.7	2.7	-	-	-	0.51

[a]SD, standard deviation.
[b]$ICC_{2,1}$ (95% CI), intraclass correlation coefficient with 95% confidence interval.
[c]SEM, standard error of the mean.
[d]MDC_{95}, minimal detectable change.
[e]Effect Size, calculated using Partial Eta squared statistics from ANOVA analysis.

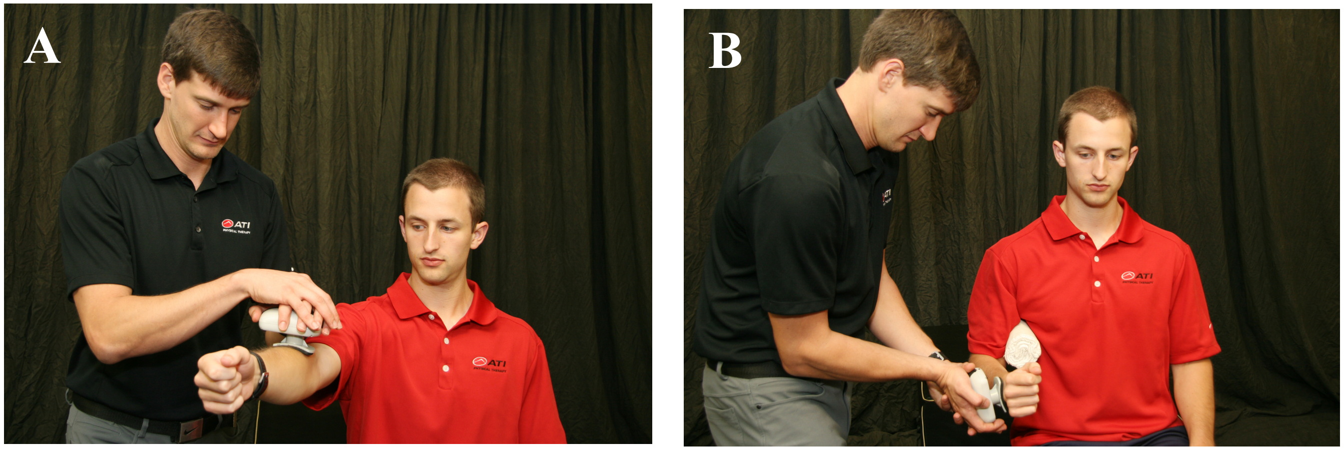

Figure 5.1 Examination of Isometric (A) Shoulder Scaption and (B) Shoulder External Rotation at 0° Strength in Seated Position

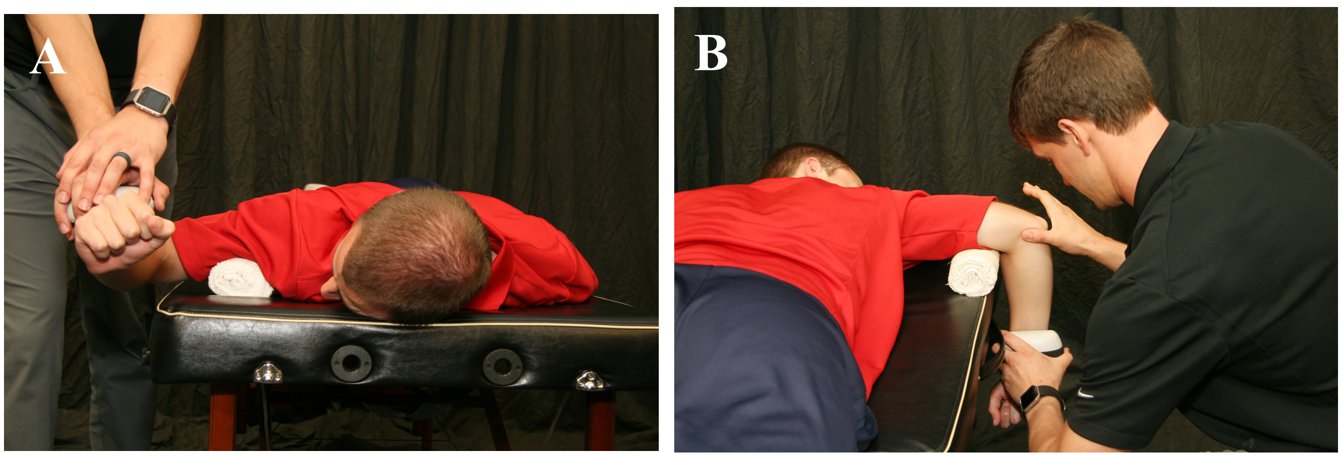

Figure 5.2 Examination of Isometric (A) Shoulder External Rotation at 90° and (B) Shoulder Internal Rotation at 90° Strength in Prone Position

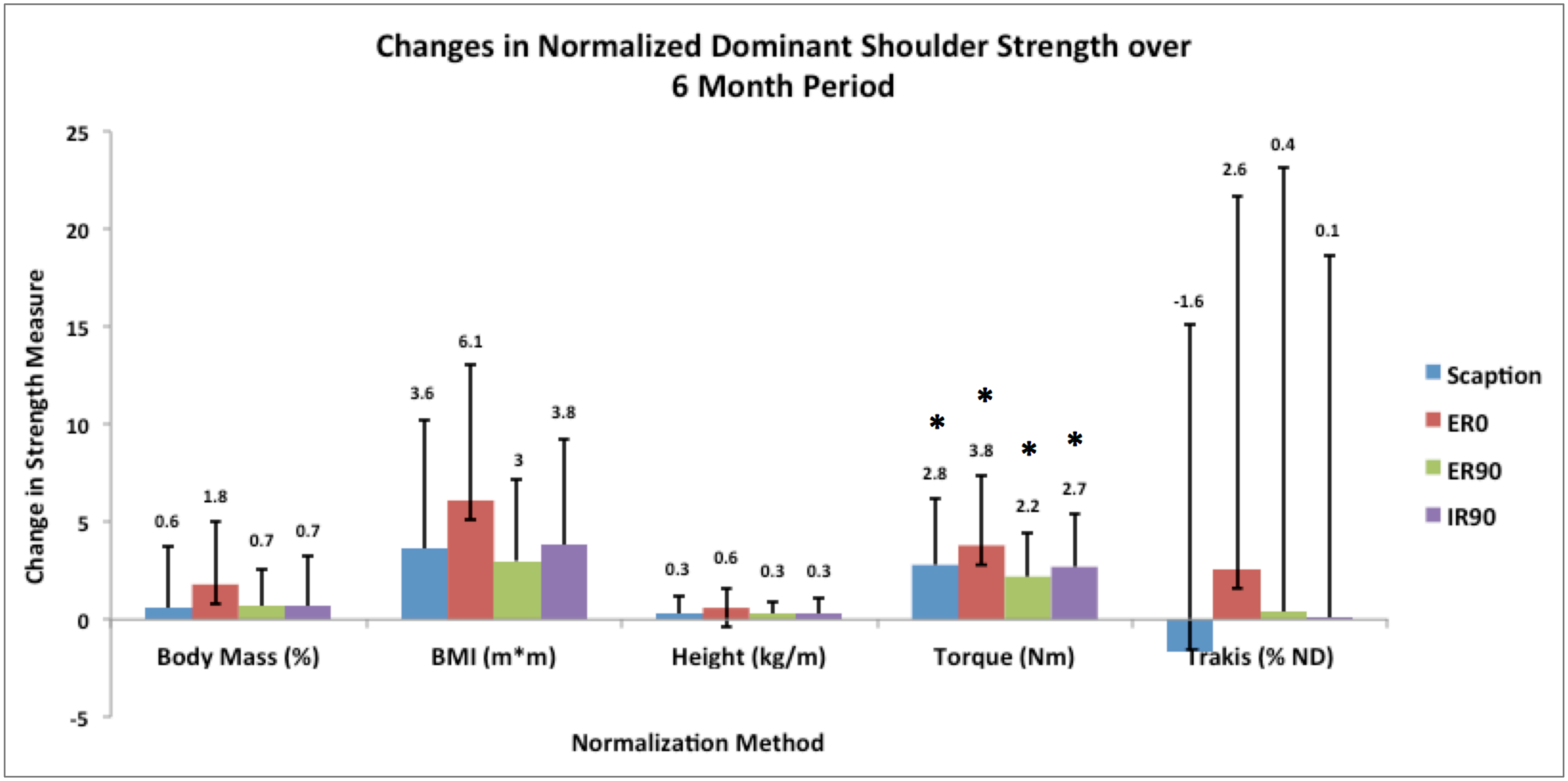

Figure 5.3 Changes in Normalized Dominant Shoulder Strength by Method over 6 Month Period

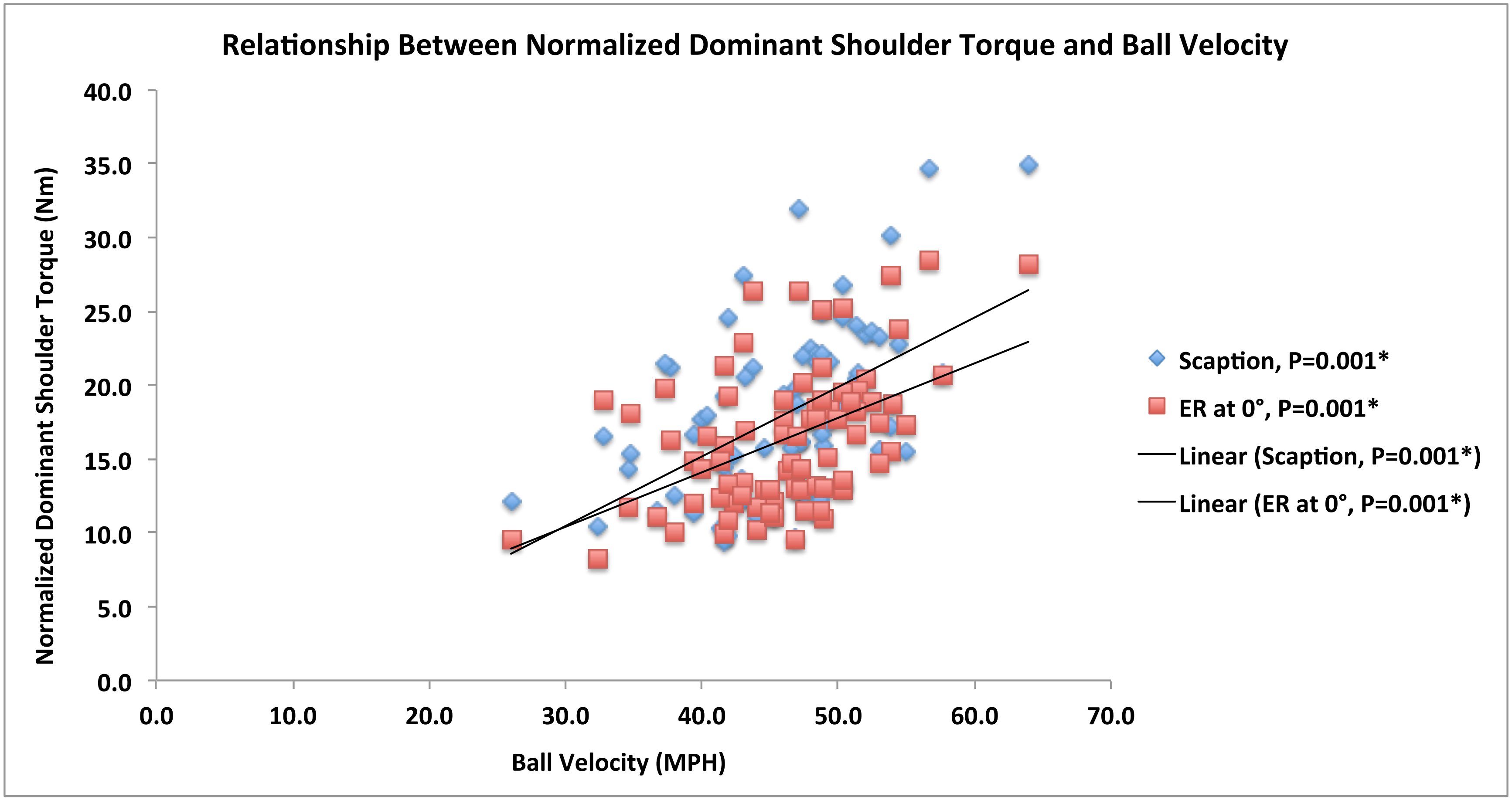

Figure 5.4 Relationship Between Normalized Dominant Shoulder Scaption Torque, External Rotation at 0° Torque and Ball Velocity

CHAPTER 6

DISCUSSION

Youth and adolescent baseball players comprise the majority of the 13-17 million athletes that participate in this sport in the U.S. each year.[4,31,51,143] The benefits of sports participation are well documented throughout the literature, however risks are also associated with these activities.[18,21,26,38,71,72] Despite increased awareness surrounding the nature of these risks, youth and adolescent athletes are reporting baseball-related overuse injuries at alarming rates.[12,19,90,91,136,140,148,154,155] The most common overuse injuries reported in baseball players are at the shoulder and elbow however there is a significant lack of epidemiologic data establishing the magnitude of upper extremity overuse injuries, particularly at the youth level.[31,137]

Determining the extent of the problem is principal in unraveling UE injury risk in youth baseball players.[151] The next step is to understand the etiology surrounding UE injury development in youth athletes by identifying population-specific risk factors, such as player position, sport specialization and participation in specialty training. Research on athlete-dependent risk factors is also needed in youth athletes, as <10% of studies include participants <18 years old.[98]

Evaluating physical measures in youth and adolescent athletes is inherently different when compared to collegiate and professional athletes.[67,68,92] This is especially true with regards to strength and performance assessments.[67,68,92] Anthropometric measures have been repeatedly linked to the body's ability to produce force and therefore muscle strength.[67-69] As height and weight fluctuate more frequently, and much more rapidly, in youth and adolescence versus adulthood, these measures become integral to the assessment of strength and performance in physically developing athletes.[70] Independent, or absolute, measures that do not take into account the current anthropometric measures of an athlete may be appropriate for use in the collegiate and professional ranks who typically demonstrate minimal changes in these measures over time.[68,70] Relying on assessment data gleaned solely from absolute measures in youth and adolescent athletes is less appropriate as they lack the ability to discern changes in physical measures from changes in body size which commonly occur in physically developing populations.[67,68,70] Accounting for these alterations in growth and development through anthropometric normalization is critical to accurately assessing athletic performance and injury risk in young athletes.[67,68,92] This led to the current study, which established UE injury incidence, examined the effects of population-specific risk factors and identified the most consistent method for normalizing isometric shoulder strength in a cohort of youth baseball players.

6.1 Upper Extremity Injuries in Youth Baseball Players

Youth baseball players demonstrated an UE injury rate of 16.3/1000 AEs, markedly higher than the injury rates previously reported in high school (4.0/1000 AEs) and collegiate players (5.83/1000 AEs).[36,137] The higher injury rate may be, in part, due to differences in the types of injuries included in each of the studies. Previous research focused on examining time-loss injuries however, based on the target population of this study, both time-loss and non-time-loss injuries were included.[90,91,116,162] Another factor that may have contributed to a higher UE injury rate in youth baseball players was the decreased number of athletic exposures recorded at this level of competition. Based on similar studies performed at the high school and collegiate levels, injury incidence was calculated using team activities (i.e. practices and games).[36,137] This study found that youth baseball players, while in season, typically attended team practices twice a week in addition to the varied number of games and tournaments played by each team. A novel finding within this study population was that the majority of athletes also participated in individual specialty training outside of team events. These activities were not included in the incidence calculations, however in retrospect, excluding individual activities may not have adequately captured the true number of athletic exposures for each youth athlete. When comparing the UE injury frequencies of this study with prior youth baseball studies, injury frequencies were lower than the previously reported values despite demonstrating a high UE injury rate (Table 6.1).[90,91,116,162] Based on the youth baseball participation patterns observed in this study, future projects should include individual training sessions in addition to team activities when capturing athletic exposure.

The most important result of our study shows that youth baseball players who specialize in baseball demonstrated greater UE injury risk compared to those who did not specialize. These findings support recent work conducted in high school athletes, that displayed increased LE injury risk in individuals who specialized in a single sport compared to those who did not.[8,99] Despite evidence showing the widespread risks associated with sport specialization in youth and adolescent athletes, its prevalence continues to increase in the U.S.[72,107] The evolution of youth sports has developed into a multi-billion dollar business as more parents and athletes aspire to achieve elite levels of play and competition.[58,71] A commonly held misconception in youth sports is that focusing on a single sport early in athlete's career will improve their future performances in that sport.[71] Current research does not support that theory and has shown that early sport specialization is not associated with an athlete's long-term success in sport and that early diversification may be more beneficial to their physical development.[84,109]

Another interesting finding of this study was that youth players who participated in additional specialty training, particularly as a pitcher, were at the greatest risk for sustaining an upper extremity injury in this cohort. This is concerning given that two-thirds of youth baseball players identified as pitchers and reported playing other positions when not pitching. Participating in formal pitching lessons, in addition to team practices and games, may derail the original purpose of age-based pitch count restrictions, by increasing the physical loads placed across a growing athlete's body. This data suggests that not only is specialization an issue but that overtraining may also contribute to the observed disparities in injury rates. Prospectively examining UE injury profiles allowed us to build on the knowledge gained from previous studies and generate a more complete picture of UE injury development in youth baseball.

6.2 Normalization Methods for Isometric Shoulder Strength in Youth Baseball Players

This study investigated five distinct methods for normalizing isometric shoulder strength to determine which had the best measurement properties for youth baseball players. The torque method demonstrated excellent intra-rater reliability, with the lowest reported SEM and MDC values of any method examined. Once normalized, dominant shoulder scaption torque was the most predictive measure with respect to ball velocity, followed by dominant shoulder ER torque at 0°. When examined individually, dominant shoulder scaption torque predicted 27% of the variation in ball velocity while dominant shoulder ER torque at 0° predicted 23% in a cohort of youth baseball players.

Dominant shoulder scaption strength and ER strength at 0° have been previously linked to upper extremity injury risk and throwing performance in baseball players.[17,44,61,97,105,148] The majority of studies examining upper extremity strength as a factor for performance and injury risk were performed in collegiate and professional athletes.[44,50,97,105] Studies have found little conclusive evidence supporting the theory of a direct relationship between baseline shoulder muscle strength and ball velocity in throwers, however shoulder muscle weakness has been repeatedly linked to injury throughout the baseball literature.[17,28,97,105,133] Magnusson[97], Mullaney[105] and Byram[17] have all shown that pitchers demonstrated deficits in dominant shoulder scaption and ER strength. While minimal data exists examining upper extremity muscle strength and injury risk in youth athletes, one study by Harada[61] compared a battery of shoulder muscle strength measures to injury risk in a cohort of Japanese youth baseball players. They found that injured athletes demonstrated greater dominant shoulder strength compared to uninjured athletes.[61]

The contradictory nature of the findings above suggests that the connection between shoulder strength and upper extremity injury risk may be different in youth athletes when compared to their collegiate and professional counterparts.[17,61,97,105] The results of the current study also indicate that the relationship between shoulder strength and throwing performance may be different in youth baseball players when compared to the collegiate and professional ranks. Youth baseball players demonstrated a positive relationship between normalized isometric shoulder torque and ball velocity while previously studies have shown no such relationship in collegiate and professional players.[17,28,97,105]

6.3 Limitations

Limitations in study design should be noted when interpreting the results of this research. Previous epidemiological studies have focused on the etiology and factors surrounding time-loss injuries and typically include all injuries across an athlete's body in their data analyses.[31,43,124,137] The current study included both time-loss and non-time-loss injuries at the shoulder and elbow when calculating injury rates. This decision was based on the target population and previous data that showed the shoulder and elbow to be two of the most commonly injured body parts in competitive baseball players.[80,124,137] The purpose of the study was to examine UE overuse injuries in youth throwers so the decision was made to exclude all non-throwing-related injuries from the data analyses. The exclusion of non-throwing injuries is an acknowledged limitation of the study as any injury has the potential to impact participation levels in baseball activities.

Sampling limitations were also present, specifically the obvious disparities in the number of youth pitchers versus position players as well as the number of specialized athletes versus multi-sport athletes reported in this study. While the groups were uneven for statistical analysis, the proportions for each position and participation level were representative of the target population being studied. To capture an adequately sized sample of youth baseball players, a 10-week rolling enrollment period was required to complete baseline evaluations. These evaluations were performed throughout the competitive baseball season. Athletes were then tracked for 6 months following individual baseline evaluations. This resulted in varied baseball participation rates among youth athletes that were likely impacted by competition level (i.e. little league baseball vs. tournament team baseball) and participation in additional sport seasons (i.e. football season, basketball season). The variability in the number of athletic exposures recorded per athlete over the 6-month calendar period, while representative of youth baseball participation rates, may have influenced our athletic exposure data collection. Gaps in baseball participation, that are unrelated to injury, can be multi-factorial in youth populations resulting in a decreased number of total exposures and an increased UE injury rate.

Hand held dynamometry has several clinical advantages such as low cost, portability and ease of use however it also has acknowledged instrumental limitations.[33,52] While extreme effort was expended to standardize all measurements and testing procedures including using a single investigator with excellent intra-rater reliability, no external stabilization was applied to the athletes during the assessments. This decision was based on feasibility and the ability to generalize our results to clinical settings, however it may have influenced our results.

One potential statistical limitation of this study was the collinearity observed between the isometric shoulder scaption torque and ER torque at 0° measures in this population. Our results indicate that either measure is predictive of ball velocity however further research is needed to determine what additional variables should be included in the model to best explain this performance measure in youth athletes. Overhead throwing is a complex motor skill that requires coordination and the proper sequencing of a series of linked movements that start in the lower extremities and ultimately culminate in ball release.[157] This statement supports our findings that isometric shoulder strength explains only a portion of the variability observed in ball velocity in young throwers. Lastly, the high levels of inter-participant variability observed in isometric shoulder ER and IR torque at 90° may have negatively influenced the predictability of these measures in youth athletes. The variability may be attributable to age-appropriate deficits in neuromuscular control in the prone overhead position however further study is needed to better understand the role neuromuscular control plays in youth baseball throwing mechanics.

6.4 Clinical Implications

The current study established UE injury incidence and identified population-specific risk factors, such as sport specialization and participation in specialty training, which increased UE injury risk in a cohort of youth baseball players. The torque normalization method for isometric shoulder strength exhibited the most consistent measurement properties in young throwers. Future longitudinal and repeated measures studies can utilize this method in physical developing populations as torque was proven to be a reliable means of assessing strength while accounting for changes in body size over time. Dominant shoulder scaption torque and shoulder ER at 0° torque were the most useful measures in predicting throwing performance in youth baseball players. The results of the current study suggest that participation patterns, risk factors and performance measures in youth baseball players are inherently different from those reported in collegiate and professional players. Additional population-specific research studies are needed to better understand injury risk, prevention and player performance in youth athletes.

6.5 Future Studies

Future epidemiologic studies should seek to capture specific sports participation and physical activity levels in youth athletes to better identify the factors and workloads associated with overtraining in sports. Identifying individual as well as team-based activities is imperative when assessing athletic exposure in these populations. Studies should also examine the effects of athlete-specific risk factors, such as height, weight, flexibility and strength, on UE injury risk and athletic performance in youth athletes, as these relationships are not well established in the literature. This data is imperative for the development and successful implementation of physical training and injury prevention programs in active youth populations.

Table 6.1. Injury Frequency Comparisons Across Multiple Youth Baseball Epidemiologic Studies

Author	***Sample Size***	***Age Range***	***Follow Up Period***	***Injury Description***	***Injury Location***	***Injury Frequency***
Lyman (2001)	298	9-12	2 seasons	Self-Reported Pain	Shoulder, Elbow	Shoulder 32% Elbow 26%
Lyman (2002)	476	9-14	1 season	Self-Reported Pain	Shoulder, Elbow	Shoulder 35% Elbow 28%
Olsen (2006)	95 – Surgical Group 45 – Control Group	14-20	12 months	Self-Reported Pitching w/Pain	Shoulder, Elbow	Surgical 67% Control 42%
Yang (2014)	754	9-18	12 months	Self-Reported Injury, Self-Reported Pain	Shoulder, Elbow	Injury 31.3% Pain 37.9%
Current Study (2017)	159	9-12	6 months	PT[*]-Confirmed Injury	Shoulder, Elbow	Shoulder 8% Elbow 5%

[*] PT, physical therapist.

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APPENDIX A – SAGE PUBLISHING PERMISSION TO REPRINT POLICY

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I WANT TO:	CLEARED PERMISSION	REQUIRES PERMISSION
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APPENDIX B – REDCAP ONLINE SURVEY SAMPLE

Youth Baseball Questionnaire

Please answer the following questions as completely as possible. If parents are completing this questionnaire in place of their child, please respond based your child's information. If you have any questions, we would be happy to answer them at any time.

Name:____ Today's Date:_________________

What is your age? ____________________

Date of Birth:_____________ Height:_______ Weight:_______ Mothers Height:_______ Father's Height:_______

What grade are you in? ☐ 3rd ☐ 4th ☐ 5th ☐ 6th ☐ 7th ☐ 8th ☐ 9th ☐ 10th ☐ 11th ☐ 12th

What organized sports do you play? ☐ Baseball ☐ Basketball ☐ Any other Sports

(List all):_______________________________

How long have you played these sports? (in years) ☐ Baseball _______ ☐ Basketball _______

☐ Any other Sports ______________

How many months of the year do you compete at your other sport(s)? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11

☐ 12

How many months of the year do you compete in more than one sport? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11

☐ 12

How many teams do you play your baseball with during the year? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Do you play on an elite level (invited team) or travel team? ☐ no ☐ yes Name of Team(s)? ____________________________

How many months of the year do you practice/play baseball? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12

How many practices per week do you average for baseball? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12

How many games per week do you average for baseball? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12

What is the maximum # of games per week you have played over the last year for baseball? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8

☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ >12

What is the minimum recovery time between baseball tournaments? In Days ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ > 7

How many months of the year do you completely rest from baseball? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12

What position do you play most often? (Choose one)

Baseball: ☐ catcher ☐ infield ☐ outfield ☐ pitcher

What other positions do you play? (Choose all)

Baseball: ☐ catcher ☐ infield ☐ outfield ☐ pitcher

Other than sport specific training, do you participate in an **in season** conditioning program? ☐ no ☐ yes

If so, is the training sport specific (e.g. agility, hitting/pitching lessons, sport specific weight lifting or conditioning)

☐ no ☐ yes Please specify, type of training:________________

Location of training:____

Other than sport specific training, do you participate in an **off-season** conditioning program? ☐ no ☐ yes

If so, is the training sport specific (e.g. agility, hitting/pitching lessons, sport specific weight lifting or conditioning)

☐ no ☐ yes Please specify, type of training:________________

Location of training:____

Do you have pain in any joint, muscle or body part while playing baseball now or within the last 6 months?

Now? ☐ no ☐ yes … Last 6 months? ☐ no ☐ yes … . If yes, which body part? _____________________________

Did you see a doctor for the injury? ☐ no ☐ yes

Ever had an injury that caused you to miss a practice or game? ☐ no ☐ yes Change position or alter practice? ☐ no ☐ yes

APPENDIX C – DATA COLLECTION SHEET

Name: ________________________________ Date:____________ Birth Date: _____________
Weight: ________ Height: ________

Mother's Height: _________ Father's Height: _________ **Dominant Arm: R L**

		LEFT		**RIGHT**	
		Trial 1	Trial 2	Trial 1	Trial 2
ROM	HRT				
	P ER@90				
	P IR@90				
	Elbow Ext				
	P HA				
STRENGTH		Trial 1	Trial 2	Trial 1	Trial 2
	Scaption				
	ER@0				
	ER@90				
	IR@90				
	Ulnar length				

Current Pain Level:

Parent's Names: _____________________________________ Phone: _________________

Email____

Current Level/# of teams___________ Position (1st, 2nd): _______________________________

Additional Sport(s): ____

Injury History:

Side of Injury	Body Part (Ex: elbow, shoulder)	Type of Injury	Sport/Position Played (when injured)	Month/Year of Injury