Upper Extremity Injury Prevention Programs for Adolescent Throwing Athletes and the Connection to Process-Oriented Assessment of Physical Competence: A Scoping Review

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A Thesis

In the Department of

Health, Kinesiology, and Applied Physiology

Presented in Partial Fulfillment of the Requirements

For the Degree of

Master of Science (Health and Exercise Science)

at Concordia University

Montréal, Québec, Canada

June 2023

CONCORDIA UNIVERSITY
School of Graduate Studies

This is to certify that the thesis prepared

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Entitled: Upper Extremity Injury Prevention Programs for Adolescent Throwing Athletes and the Connection to Process-Oriented Assessment of Physical Competence: A Scoping Review

and submitted in partial fulfillment of the requirements for the degree of

Master of Science (Health and Exercise Science)

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Abstract

Upper Extremity Injury Prevention Programs for Adolescent Throwing Athletes and the Connection to Process-Oriented Assessment of Physical Competence: A Scoping Review

Hengameh Bazrafshan

Children and adolescent athletes participating in throwing sports are particularly susceptible to upper extremity overuse injuries compared to adults, often attributed to factors such as poor technique and balance. This study aims to explore the potential correlation between process-oriented assessments of throwing skill and injury prevention in youth athletes. Through a systematic search of databases including PUBMED, MEDLINE, and SPORTDiscus, interventions focusing on upper extremity injury prevention programs and process-based physical competence assessment tools for throwing skill were identified. Criteria for study inclusion encompassed physically and mentally healthy participants aged 8-19 years, with exclusion criteria eliminating review papers, non-English language publications predating 2000, inaccessible full texts, and samples involving individuals with existing shoulder or elbow pain or injury. While formal risk of bias assessment was not conducted due to study heterogeneity, our findings indicate commonalities in process-based assessment criteria across throwing phases, highlighting specific pitching kinetic and kinematic flaws integral to evaluating technique quality and effectiveness. Despite this, existing injury prevention programs inadequately address the multifactorial nature of throwing injuries in youth athletes, necessitating further investigation into modifying throwing techniques through process-oriented physical competence assessment tools. Prospective assessments should prioritize integrating technique-oriented biomechanical analyses within injury prevention strategies to mitigate upper extremity injury risk effectively.

Acknowledgments

To my family, whose unwavering belief in me has been my cornerstone. Maman, Baba, your boundless love and encouragement have given me the strength to overcome challenges and pursue my dreams. Your sacrifices and understanding have been the wind beneath my wings, propelling me forward in this pursuit of knowledge.

To my beloved ones, who have become my family away from home, Sébastien, Anahita, and Taraneh. Your camaraderie, laughter, and endless conversations have illuminated even the most arduous days. Your presence has transformed the halls of academia into a place of warmth and shared growth.

A special mention is reserved for my confidante and writing companion, Yasmin. Your brilliance, patience, and unwavering belief in the power of words have been instrumental in shaping the ideas presented here. Without your guidance and meticulous feedback, this thesis would remain a mere collection of thoughts.

My heartfelt gratitude extends to my esteemed committee members, whose insights and critiques have been pivotal in refining this work. Your dedication to academic excellence has been an inspiration throughout this endeavor.

I am indebted to my thesis supervisor, Dr. DeMont for his mentorship. Your guidance has been a light, illuminating new perspectives and shaping the direction of this research.

The completion of this thesis stands as a testament to the contributions of those mentioned above. Each one has played an integral role in this journey, enriching it with their unique presence and influence. It is with a heart full of gratitude that I express my appreciation to each individual who has been a part of this remarkable chapter.

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1.1.1 Children and Adolescents Sport Participation and Upper Extremity Injuries

Sport participation refers to engaging in physical activity or competition that involves a set of rules or objectives, often with a specific outcome or goal (Croci et al., 2021). Participation rates in organized sports have steadily increased over the past few decades among children aged 7 to 12(Benjamin & Hang, 2007; Trentacosta, 2020). Along with the increase in participation, there has been a rise in the frequency and intensity of sports training and competition among young athletes, resulting in an increase in the incidence of sports-related injuries (Benjamin & Hang, 2007; Zaremski et al., 2019).

Notably, children account for a significant portion of all sports injuries, with upper extremity injuries representing 27.7% of these injuries (Merkel, Donna L. & Molony, Joseph T., 2012). Physiologically, children's bones contain more collagen and cartilage compared to the ossified bones of adults (Croci et al., 2021). Additionally, children exhibit ligamentous laxity, open epiphyseal growth plates, underdeveloped musculature, and decreased balance and coordination, rendering them susceptible to unique upper extremity injuries (Croci et al., 2021; Franklin & Weiss, 2012). The weaker bones of childhood, relative to ligaments and tendons, coupled with ongoing bone development, predispose children to fractures resulting from stresses across these structures (Franklin & Weiss, 2012; Merkel, Donna L. & Molony, Joseph T., 2012).

As children transition into adolescence, aged 13 to 17, their participation in organized sports continues to increase (Benjamin & Hang, 2007; Trentacosta, 2020). With this increased participation comes a heightened risk of sports-related injuries among adolescent athletes (Croci et al., 2021; Zaremski et al., 2019). Upper extremity injuries remain prevalent in this age group, accounting for a significant proportion of sports injuries, representing 37.3% in high school athletes (Merkel, Donna L. & Molony, Joseph T., 2012; Zaremski et al., 2019). Adolescents may exhibit characteristics such as increased bone density due to growth spurts, but their bones may still be in the process of maturing, leading to specific injury patterns (Kerssemakers et al., 2009). Moreover, adolescents may engage in more high-impact sports activities and risky behaviors compared to children, contributing to their unique injury profile (Benjamin & Hang, 2007; Lee et al., 2021).

Injuries during childhood and adolescence have the potential for life-long effects, so mitigating injury risks from physical activity in these age groups is necessary (Miller et al., 2018). It is important to monitor the transition of children's fundamental movement skills into sport-specific movements to adequately prepare them for more challenging physical activities. Neglecting this transition could leave them vulnerable to injury and long-term consequences (Miller et al., 2018).

1.1.2 Injury Mechanism

Understanding the causes of sport injuries is achievable through the precise description of the inciting event, called injury mechanism (Bahr, 2005). *Injury mechanism* is "the fundamental physical process responsible for a given action, reaction or result" (Bahr, 2005). An acute injury mechanism is typically caused by a sudden, traumatic event, such as a fall, collision, or twist, and symptoms tend to develop immediately. If an acute injury is not healed properly, it can result in a chronic injury. Chronic injury mechanism is an injury that has been present for a long period of time, usually more than three months. In addition to an acute trauma, chronic injuries can also be caused by overuse injury mechanism, particularly in athletes or individuals who engage in repetitive physical activities. An overuse injury is a type of injury that occurs as a result of repetitive microtrauma to a particular part of the body.

Upper Extremity Acute Injuries

Upper extremity acute injuries in children and adolescent athletes can occur due to a prevalent mechanism called “a fall onto an outstretched arm (FOOSH)” (Benjamin & Hang, 2007; Carson et al., 2006; Merkel, Donna L. & Molony, Joseph T., 2012). A FOOSH can cause a variety of injuries including fractures, dislocations, and ligament sprains in different parts of the outstretched arm. (Benjamin & Hang, 2007). For example, proximal humeral fracture is a common incident in adolescent baseball pitchers, presented with localized pain in the proximal humerus or anterior shoulder (Benjamin & Hang, 2007). Radial and ulnar collateral ligaments sprains due to a direct trauma occur frequently in children between the ages 5 to 10 years old (Benjamin & Hang, 2007; Merkel, Donna L. & Molony, Joseph T., 2012). Distal radius or ulnar fractures in children and a scaphoid fracture in middle school and adolescent athletes, are common wrist and hand FOOSH-type sport-related injuries (Carson et al., 2006).

Upper Extremity Overuse Injuries

Upper extremity overuse injuries occur in athletes who exert repetitive submaximal forces on their arms when training demands exceed their body’s physiological ability to repair itself (Kerssemakers et al., 2009; Trentacosta, 2020). Overuse injuries often happen in children who participate in a “year-round training in a single sport, to the exclusion of other sports” which is referred to as sport specialization (Confino et al., 2019; Croci et al., 2021). Repetitive movements specific to a single sport can lead to the adoption of specific movement patterns and techniques (Kraan et al., 2019). If these movements are performed incorrectly or with inefficient biomechanics, they can place excessive stress on certain muscles, tendons, and joints, increasing the risk of overuse injuries (Chalmers et al., 2017; Fleisig et al., 2009).

If we consider the scenario of a child who specializes in throwing sports but possesses good biomechanics; while the risk of overuse injuries may be reduced, it does not eliminate the possibility entirely (Zaremski et al., 2019). Conversely, a child with poor biomechanics may be at a heightened risk of overuse injuries, even without engaging in sport specialization (Fleisig et al., 2009). While sport specialization is recognized as a risk factor for overuse injuries (Zaremski et al., 2019), the focus of this paper lies predominantly on biomechanics. For instance, when an overhead throwing athlete develops faulty throwing mechanics due to the repetitive nature of the activity, they will put increased strain on their shoulder and elbow joints (Kraan et al., 2019).

Although overuse and acute injuries have different causes and symptoms (Benjamin & Hang, 2007), there can be a relationship between the two (Kraan et al., 2019). One possible relationship is that an overuse injury can increase the risk of an acute injury (Kraan et al., 2019). When a person has an overuse injury, the affected area may be more susceptible to an acute injury (Kraan et al., 2019; Tisano & Estes, 2016). For example, a young pitcher who continues to throw despite experiencing pain due to little league shoulder or elbow may be at risk for an ulnar collateral ligament tear (Tisano & Estes, 2016). Conversely, an acute injury can lead to an overuse injury if the person tries to compensate for the injury by overusing another part of the body (Kraan et al., 2019). For example, a baseball player with stress fracture may begin to rely more on the other arm by adjusting their throwing mechanics, such as using the non-dominant arm more frequently or altering their grip (Kraan et al., 2019). In an attempt to compensate for the injury, the player might also modify their hitting mechanics (Fleisig et al., 2009), favoring the uninjured arm for greater support (Davis et al., 2009; Fleisig et al., 2009). These adjustments can lead to an increased workload in the other arm and increase the risk of developing rotator cuff tendinitis or medial epicondylitis (Bencke et al., 2018; Davis et al., 2009).

1.1.4 The Throwing Motion

Throwing Phases

There are six distinct phases to the throwing motion that are universal across all throwing sports: (Chu et al., 2016; Kerssemakers et al., 2009):

1. Wind-up phase: starts with the first movement of the leading leg and ends with it reaching its highest point. During this phase, the lower body prepares a stable base for energy transfer by putting the body's centre of gravity over the back leg with minimal stress. This is important for the next phases to generate the most momentum.
2. Early cocking phase: begins once the lead leg reaches its maximum height and ends when the lead foot contacts the pitching mound. During this phase, the shoulder is abducted and externally rotated.
3. Late cocking phase: occurs between lead foot contact with the pitching mound and the point of maximal external rotation of the throwing shoulder. The activity of the rotator cuff muscle applies great shear forces to the glenohumeral joints.
4. Acceleration phase: it is the time between maximum external rotation of the shoulder and the realising of the ball. In this phase, the elbow joints are under tremendous stress, compression, and rotational forces.
5. Deceleration phase: occurs when the ball is released, and maximum humeral internal rotation and elbow extension is reached. This is often considered the most violent and dangerous phase of the pitching motion because it causes the greatest joint loading during throwing.
6. Follow-through phase: occurs when the body and the arm continue to move forward until the motion is over. This creates glenohumeral stability and prevents anterior luxation.

Throwing Technique, Good vs Poor

The throwing phases delineate the fundamental components of a proficient throwing motion, which is imperative to delve deeper into the nuances of throwing technique (Chu et al., 2016). Building upon the descriptions provided in the throwing phases, good technique is characterized by meticulous attention to detail, ensuring that each movement seamlessly transitions into the next with minimal energy loss and maximal force production (Chu et al., 2016). From the initial wind-up to the final follow-through, athletes executing good technique exhibit fluidity, balance, and synchronization across all body segments, culminating in a powerful and controlled release of the ball (Oyama, 2012).

In contrast, poor throwing technique manifests in deviations from the optimal movement patterns outlined in the throwing phases, resulting in inefficiencies, diminished performance, and heightened injury risk (Oyama, 2012; Shitara et al., 2021). Common examples of poor technique include overstriding, arm drag, early trunk rotation, and incorrect elbow positioning, each of which can compromise the integrity of the throwing motion and place undue stress on the shoulder and elbow joints (Christoffer et al., 2019; Chu et al., 2016).

Throwing Biomechanics

Throwing is a complex skill that involves the entire body, beginning with the lower limbs and progressing through the trunk to the upper limbs, to generate kinetic energy for ball velocity (Chu et al., 2016; Shitara et al., 2021). The mechanical linkage between the body segments, called the kinetic chain, distributes forces to minimize stress on the throwing arm during high-velocity overhead throwing, such as baseball pitching (Bencke et al., 2018; Cools et al., 2021). Effective utilization of the kinetic chain ensures that each body segment contributes efficiently, transferring energy from the legs and hips through the torso, shoulder, arm, and hand during the throwing motion (Cools et al., 2021).

Optimal throwing technique is essential for translating the benefits of the kinetic chain into efficient throwing mechanics (Chu et al., 2016). Elements such as grip, wind-up, stride, arm motion, and follow-through are integral components of proper technique that maximize energy transfer while minimizing stress on specific joints or muscles (Ellenbecker & Aoki, 2020). By maintaining consistent and correct biomechanics throughout the throwing phases, athletes can enhance throwing efficiency, reduce the risk of injuries, and optimize performance (Chu et al., 2016).

1.1.5 Risk Factors of Throwing Upper Extremity Injuries

There are intrinsic and extrinsic sport-related injury risk factors. Intrinsic risks, such as genetics, anatomy, or pre-existing conditions, are related either to the physical characteristics of the individuals (e.g., age, sex, somatotype, previous injury), or to their psychological traits (e.g., confidence, fear of failure) (Kerssemakers et al., 2009). Although some intrinsic factors may be altered through medical intervention, they are generally non-modifiable (Kerssemakers et al., 2009).

Extrinsic risk factors, such as exposure, training, environmental conditions, and equipment, are associated with individuals' environment or lifestyle (Kerssemakers et al., 2009). Some of these factors, like poor technique or body position, can be addressed through intervention training, such as observational correction during training sessions, to prevent potential injuries in overhead athletes (Sakata et al., 2019; Wright et al., 2021). All these factors may be observed in upper body, trunk, or lower body while athletes are performing the overhead throwing motion. Modifiable risk factors such as reduced range of motion, strength deficit, and poor balance may affect the proper technique (Bencke et al., 2018).

Poor Throwing Technique

Poor throwing technique due to improper mechanics can place excessive stress on the muscles, tendons, and ligaments in shoulder and elbow, leading to overuse injuries (Ellenbecker & Aoki, 2020). . It is crucial for athletes to work on proper throwing mechanics, maintain adequate flexibility and strength, and improve their balance to reduce the likelihood of injury.

Reduced Range of Motion

Reduced range of motion refers to a limitation in the ability of a joint to move through its normal range of motion, and is caused by a variety of factors such as muscle imbalances and joint instability (Cools et al., 2021). In the upper extremities, reduced range of motion in glenohumeral internal rotation and elbow extension could cause overuse injuries as the limited mobility increases stress on those joints (Cools et al., 2021; Sakata et al., 2019; Shitara et al., 2021; Wright et al., 2021). The overall reduced range of motion can also affect the throwing technique as the body tries to compensate for the altered movement pattern, affecting performance (Sakata et al., 2019). For instance, a pitcher experiencing limited glenohumeral internal rotation may subconsciously alter their throwing mechanics to compensate for the restricted movement, potentially leading to changes in arm slot or release point (Mayes et al., 2022). These compensatory adjustments affect performance and increase the risk of injury due to the altered biomechanics (Sakata et al., 2019).

Reduced range of motion in the trunk or lower extremity can potentially result in shoulder or elbow injury (Chu et al., 2016; Hamano et al., 2021; Shitara et al., 2021). Limited range of motion in the trunk, hips, or legs can lead to compensatory movements in the upper extremities, which can place increased stress on the shoulder or elbow joints (Hamano et al., 2021). For example, if an athlete has reduced hip mobility, they may compensate by arching their lower back when performing an overhead throwing movement, which can increase the risk of shoulder impingement or rotator cuff injury (Hamano et al., 2021)

Strength Deficits

Muscle strength deficiency can increase the risk of upper extremity injuries by altering joint mechanics, increasing stress on other structures, and decreasing control and accuracy during the throwing motion (Chu et al., 2016). Particularly, strength deficiency in rotator cuff muscles (supraspinatus, infraspinatus, teres minor, and subscapularis) can lead to shoulder instability causing tears to these muscle as well as a secondary impingement syndrome (Chu et al., 2016; Cools et al., 2021; Hamano et al., 2021; Wright et al., 2021).

Additionally, decreased hip and knee extensor strength alters the transfer of kinetic energy to the upper extremity, affecting ball velocity and throwing mechanics (Chu et al., 2016). Furthermore, the disruption in the kinetic chain may lead to compensatory movements and altered stress distribution throughout the body during the throwing motion. These compensations can result in inefficient movement patterns, reduced accuracy, and increased risk of injury (Bencke et al., 2018; Chu et al., 2016)

Balance Deficits

Balance is defined as the ability of an athlete to maintain control and stability of their body during movement and in static positions (Garrison et al., 2013). Balance is a complex motor skill that relies on the integration of multiple physiological systems, including vision, vestibular function, and musculoskeletal control (Eriksrud et al., 2019). Therefore, athletes with decreased balance may be at higher risk for injury as their movement coordination could be affected (Ellenbecker & Aoki, 2020; Hannon et al., 2014). Endo and Sakamoto (2014) reported that baseball players with poor balance had a significantly higher incidence of shoulder and elbow injuries compared to those with better balance.

Deal et al. (2020) reported that poor lower body balance and neuromuscular control may contribute to increased stress on the elbow joint during throwing by altering the kinetic energy transfer throughout the body.

1.1.6 Upper extremity Injury Prevention Programs

To address upper extremity injury risk factors, prevention programs typically involve a combination of exercises and drills, designed to improve throwing mechanics, strengthen the upper extremities and core muscles, and promote overall flexibility and range of motion (Cools et al., 2021; Sakata et al., 2019; Wright et al., 2021). Incorporating balance exercises into a comprehensive injury prevention program may be a beneficial strategy for athletes at risk of shoulder or elbow injuries (Deal et al., 2020; Endo & Sakamoto, 2014; Eriksrud et al., 2019). Some common exercises and tools used in upper extremity injury prevention programs include:

1. Resistance bands for shoulder and elbow strengthening exercises (Wilk et al., 2021).
2. Weighted balls for plyometric exercises and improving arm speed (Oyama & Palmer, 2022)
3. Medicine balls for core and rotational strength exercises (Oyama & Palmer, 2022)
4. Foam rollers for self-myofascial release and soft tissue mobilization (Ozden & Yesilyaprak, 2021)
5. Stretching and warm-up routines for the upper extremities and core muscles (Oyama & Palmer, 2022; Wilk et al., 2021)

Prevention programs also utilize education and training on proper throwing mechanics, rest and recovery strategies, and injury prevention strategies such as monitoring total throwing volume and using appropriate rest periods (Cools et al., 2021).

One example of a comprehensive upper extremity injury prevention program is the American Sports Medicine Institute (ASMI) Throwers Ten Exercise Program. This program was is designed to help prevent throwing-related injuries in baseball players, but it can be modified for athletes in other throwing sports (Glanzer et al., 2021; Reinold et al., 2002; Wilk et al., 2011).

The modified version of the ASMI Throwers Ten Exercise Program for children and adolescent athletes include (Wilk et al., 2021):

1. Education and Training: Coaches, parents, and athletes should receive education and training on proper throwing mechanics, rest and recovery strategies, and injury prevention strategies.

2. Warm-up and Stretching: Athletes should perform a dynamic warm-up and stretching routine before throwing, with a focus on the upper extremities and core muscles.
3. Strengthening and Conditioning: Athletes should perform exercises to strengthen and condition the muscles used in throwing motions, with a focus on the upper extremities and core muscles. This can include exercises with resistance bands, weighted balls, medicine balls, and bodyweight exercises.
4. Technique Training: Athletes should receive training on proper throwing mechanics and techniques to reduce stress on the arm and shoulder during throwing motions.
5. Rest and Recovery: Athletes should take appropriate rest periods between throwing sessions to allow for recovery and avoid overuse injuries.
6. Monitoring Throwing Volume: Coaches and parents should monitor the total amount of throwing that athlete perform to adjust their training and competition schedules accordingly to avoid overuse injuries.

Overall, the ASMI Throwers Ten Exercise Program prioritizes the importance of education, proper technique, and rest and recovery in reducing the risk of overuse injuries in children and adolescent athletes who participate in throwing sports (Cools et al., 2021; Wilk et al., 2021; Wright et al., 2021). By addressing these factors and incorporating injury prevention strategies into training and competition, young athletes can reduce their risk of overuse injuries and maintain healthy and sustainable athletic careers (Cools et al., 2021; Sakata et al., 2019).

1.1.7 Physical Competence Assessment Tools

Injury prevention in sports involves recognizing and nurturing fundamental movement skills, that are essential skills for childrens' physical development and later participation in sports and physical activities (Cohen et al., 2014; Wick et al., 2017). These skills include locomotion (e.g., running, jumping, hopping), object manipulation (e.g., throwing, catching, kicking), and stability (e.g., balancing, twisting, bending) (Lopes et al., 2020). Fundamental movement skills lay the foundation for physical competence, which is the ability to perform a variety of physical activities effectively and proficiently (Wick et al., 2017). Physical competence involves the application and integration of fundamental movement skills in a range of physical activities and sports (Wick et al., 2017). For example, if a child has developed the throwing skill, they can apply it to a range of activities such as throwing a ball in a baseball game (Cohen et al., 2014).

Physical competence evaluations focus on either product- or process-oriented scoring approaches (Hulteen, Barnett, et al., 2020). Product oriented assessment tools (e.g., Get Skill Get Active, Bruininks-Oseretsky Test of Motor Proficiency-2nd edition, Movement Assessment Battery for Children-2nd edition) focus on evaluating the outcome of a movement or task using a quantitative measure. Product oriented assessments are often used to evaluate an individual's overall level of proficiency, such as speed, accuracy, or distance. These assessments are often used to evaluate athletic performance efficiency or to determine readiness for competition (Hulteen, Barnett, et al., 2020; Lopes et al., 2020).

Process-oriented assessment tools (e.g., Test of Gross Motor Development, CHAMPS Motor Skill Protocol) focus on evaluating the individual's movement patterns, techniques, and strategies used to complete a task or movement (Gallahue D. L. Ozmun J. C. & Goodway J., 2012) using a quantitative measure). For example, to assess a baseball swing, the evaluator may focus on the player's body positioning, weight transfer, hand placement on the bat, and swing mechanics as they approach the ball (Christoffer et al., 2019). The outcome of whether the ball is hit or not is not the primary focus of the assessment. These tools allow for a more detailed analysis of the player's strengths and weaknesses in their swing mechanics, which can then be used to guide training and practice (Gallahue D. L. Ozmun J. C. & Goodway J., 2012).

1.1.8 Assessments of the Throwing Skill

Throwing is one of the most frequent skills, evaluated by physical competence assessment tools. Hulteen et al. (2020) reported that among the 57 unique skill assessment tools that they reviewed, the most commonly assessed skill was the overhand throw (n = 33; 58%).

Process-oriented and product-oriented tools use different criteria to evaluate the same skill. For example, The Get Skill Get Active (GSGA), the Bruininks-Oseretsky Test of Motor Proficiency-2nd edition (BOT-2), and the Movement Assessment Battery for Children-2nd edition (MABC-2) all use the following instructions for evaluating the throwing skill (Barnett et al., 2009; Deitz et al., 2007):

- The child stands behind a designated line or starting point.
- The child is instructed to throw a ball as far as they can towards a target.
- The distance between the starting point and the target is recorded in feet and inches.
- The child is allowed two attempts, and the best distance is recorded.
- The child is then instructed to perform the throw with their non-dominant hand, and the best distance is recorded.

While age ranges are different, all the three assessment tools above mainly focus on the throwing distance and ball speed in children and adolescents (Hulteen, Barnett, et al., 2020).

Similarly, the Test of Gross Motor Development (TGMD) and CHAMPS Motor Skill Protocol (CMSP) use similar instructions for the throwing task, all of which focus on the process-oriented approach. The general criteria for throwing evaluation include (Ulrich, Dale A., 2019; Williams et al., 2009):

- Stepping with the opposite foot to the throwing arm,
- Swinging arm back behind the body to load,
- Bringing the arm forward in an upward motion,
- Following through with the throw by extending the arm and fingers toward the target,
- Releasing the ball below head level,

- Throwing the ball in a forward direction.

Disadvantages of a process-oriented assessment include the complexity of performing the evaluation, the time required to accurately assess the movement, and the expensive costs.

1.2 Rationale

This study aimed to explore the link between “upper extremity injury prevention programs” and “physical competence assessment tools” for the throwing skill in children and adolescent athletes. Currently, upper extremity injury prevention programs lack cohesion, with variations in program duration, frequency, exercise types, study designs, and conflicting results (Cools et al., 2021; Huckabee, Hannah, 2022; Wright et al., 2021). Additionally, there is a dearth of prevention programs that emphasize technique modification through instructions and feedback, which is a priority in youth sports (Oyama, 2012).

While previous research highlights the importance of physical competence in injury risk (Miller et al., 2018, 2020; Padua et al., 2018), there remains a gap in understanding this relationship, especially in object manipulation skills among young athletes.

Process-oriented assessment tools provide valuable guidance on proper throwing mechanics, emphasizing key phases such as the stride, wind-up, and follow-through (Bencke et al., 2018; Chalmers et al., 2017; Ulrich, Dale A., 2019). These tools underscore the importance of the kinetic chain and its role in mitigating upper extremity injury risk (Christoffer et al., 2019; Mayes et al., 2022).

Given the importance of proper technique in injury prevention, particularly in young athletes, process-oriented assessment tools offer valuable opportunities to mitigate upper extremity injury risk (Bencke et al., 2018; Davis et al., 2009; Miller et al., 2018). Tailoring prevention strategies to address the physiological differences between children and adults is crucial (Mautner & Blazuk, 2015), emphasizing the need for technique-focused approaches in youth sports (Davis et al., 2009; Oyama, 2012).

The absence of dedicated upper extremity injury prevention programs for young athletes underscores the need for comprehensive approaches that integrate process-oriented assessments with evidence-based strategies (Logan et al., 2017). An integrated approach combining process-oriented and product-oriented assessments, along with targeted interventions, holds promise in reducing injury risk and enhancing athletic performance (Al Attar et al., 2021; Matsel et al., 2021). Further research is warranted to delineate the unique injury risk factors in young athletes and develop tailored injury prevention strategies and assessment tools for this population (Looney et al., 2021).

Conducting a scoping review enables a comprehensive assessment of the literature, facilitating the identification of research gaps and informing evidence-based strategies for injury prevention in young athletes. (Arksey & O'Malley, 2005) By synthesizing existing evidence, this study aims to promote proper technique and contribute to injury prevention efforts in children and adolescents' upper extremity injury. Identification of the Research Questions

The main research question guiding this review: "Is there evidence of a relationship between process-oriented assessment tools and injury prevention programs for the throwing motion?" This question sets the primary focus of the review and underscores the investigation into the effectiveness of process-oriented assessment tools in preventing upper extremity injuries among children and adolescent throwing athletes.

To address this main question effectively, several sub-questions are considered:

- What types of strategies have been developed and implemented in the realm of upper extremity injury prevention programs for throwing athletes?

- What existing research informs the development and implementation of these strategies?
- What are the strengths, limitations, and gaps in the strategies identified?
- Have these strategies considered contextual factors related to implementation?
- What are the outcomes associated with these strategies?

Our objectives were: (1) to review the current literature available on upper extremity injury prevention programs for children and adolescent overhead throwing athletes, (2) to review the current literature available on process-based physical competence assessments of the throwing skill, (3) to investigate the potential similarities between process-based tools and injury prevention programs, (4) to elucidate areas where research may be lacking to inform future research.

Chapter 2: Manuscript

2.1 Introduction

Sport participation has witnessed a notable rise, encompassing various physical activities and competitions governed by specific rules and objectives (Croci et al., 2021). The surge in organized sports engagement among children and adolescents has yielded numerous benefits; however, it has also paralleled an escalation in sports-related injuries (Benjamin & Hang, 2007; Trentacosta, 2020). Upper extremity injuries, notably affecting the shoulder and the elbow, have emerged significantly among adolescent throwing athletes engaged in sports such as baseball, cricket, handball, softball, and water polo (Kerssemakers et al., 2009; Magra et al., 2007; Zaremski et al., 2019). Additionally, the unique physiological characteristics of adolescents (i.e., increased bone plasticity, open growth plates, and ligamentous laxity) put them at a high risk of sports injuries (Croci et al., 2021; Franklin & Weiss, 2012).

The demands of repetitive and high-velocity throwing motions (Kraan et al., 2019), combined with inadequate training (Asker et al., 2017; de Lira et al., 2023; Shitara et al., 2017) and poor biomechanics (Chalmers et al., 2017; Christoffer et al., 2019; Oyama, 2012), contribute to the vulnerability of youth throwing athletes to injuries that can have lasting impacts on their performance and careers (Cools et al., 2021). As a result, the development of effective injury prevention strategies is of paramount importance to ensure the long-term health and success of young athletes (Lau & Mukherjee, 2023). In the realm of injury prevention for overhead athletes, various programs have been designed to mitigate the risk of shoulder and elbow injuries. These programs often prioritize strength, flexibility, and balance through exercise-based interventions (Hamano et al., 2021; Lau & Mukherjee, 2023; Matsel et al., 2021; Sakata et al., 2019). By targeting these aspects of physical fitness, they aim to enhance overall resilience and reduce the susceptibility to injury. However, a notable gap exists in these programs; while they focus on physical attributes, they often overlook a critical factor - proper technique (Hamano et al., 2021; Matsel et al., 2021). This omission is significant as faulty movement patterns and suboptimal biomechanics can contribute to injury risk, (Bencke et al., 2018; Davis et al., 2009; Fehringer et al., 2017) even in athletes who exhibit commendable physical attributes (Fleisig et al., 2009).

Fundamental movement skills form the basis of physical development, and influence an individual's ability to engage in sports and physical activities effectively (Cohen et al., 2014). These skills encompass locomotor, manipulative, and stability skills (Hulteen, Barnett, et al., 2020), which collectively constitute physical competence (Hulteen, True, et al., 2020; Whitehead, 2001). Process-based assessment tools have emerged as valuable instruments to evaluate movement quality and technique (Miller et al., 2018). Unlike outcome-based assessments that are product oriented (measure the result of a movement), process-based tools delve into the nuances of movement execution (Hulteen, True, et al., 2020; Logan et al., 2017), offering insights into biomechanics and identifying areas for improvement (Brtva et al., 2021). These tools, therefore, provide a comprehensive understanding of an athlete's strengths and weaknesses in movement patterns (Fehringer et al., 2017; Miller et al., 2018).

Recently, a literature review has proposed the interconnectedness of injury prevention and process-based physical competence assessment tools (Miller et al., 2018). Miller et al. (2018) underscored this connection by demonstrating the overlap between the movement skills evaluated by injury prevention programs and those assessed by process-based tools. Notably, both injury prevention programs and process-based assessments emphasize proper body positioning and technique during movement tasks (Miller et al., 2018). This alignment suggests that a comprehensive injury prevention approach should extend beyond physical attributes to encompass movement quality. The Child-Focused Injury Risk Screening Tool (Child-FIRST), developed by Miller et al. (2020), exemplifies this integration. This process-based assessment evaluates lower extremity injury risk in children through the examination of movement skills, highlighting the potential impact of technique on injury susceptibility (Miller et al., 2020).

Current scoping review endeavors to explore the relationship between upper extremity injury prevention and process-based physical competence assessment tools, aligning with our central research question. By bridging the gap between injury prevention programs and biomechanical evaluations, we aim to develop a more holistic understanding of injury risk factors in overhead athletes. Through a comprehensive examination of technique-oriented interventions, our review aimed to assess injury prevention strategies. By providing insights into evidence-based practices, we aim to inform future initiatives aimed at promoting the long-term well-being and health outcomes of young athletes engaged in overhead sports.

2.2 Methods

2.2.1 Search Strategy for Study Identification

The databases utilized during the search were: PUBMED, MEDLINE, and SPORTDiscus. We cross-referenced studies found in systematic literature reviews to add additional articles not found during database searches. Along with using specific terms to filter through the determined databases (see Table 1), the timeframe for publication for selected articles was extended from 2000 to May 2023.

We selected papers if they included physically and mentally healthy children or adolescents (samples younger than 12 years old were classified as children, and samples with an age range between 13 and 19 years were classified as adolescents). Intervention studies were included if they used ‘upper extremity injury prevention programs’ and/or ‘process-based physical competence assessment tools for throwing skill’. Regarding injury prevention, we collected studies that employed shoulder and/ or elbow injury prevention programs, including exercise protocols, overuse restriction guidelines, and technique-focused instructions. In terms of proper technique, we analyzed biomechanical risk factors including improper throwing mechanics and kinetic chain deficits. Throughout the different throwing phases, specific body positions and throwing techniques were identified, along with the corresponding risk factors that were identified in the literature.

The need for process-based assessments, lead us to collect existing valid and reliable motor competence assessment tools that included object manipulation skills and their evaluation criteria that could be associated with upper extremity injury prevention programs.

From these search criteria we included we included randomized control trials, observational studies, measurements, and validity studies published in the English language. We compared the elements of the throwing skill across all the studies on “process-based physical competence” and “injury prevention” assessments. Our goal was to investigate if and how well these elements as measured by the intervention studies, correspond, or overlap. To do so, we used keywords to filter out concepts related to upper extremity injury risk factors and prevention strategies that are similar to the process-based assessment tool criteria for throwing skill.

The search strategy included the population, intervention, comparison, and outcome approach and a combination of search terms, synonyms, truncation, and Boolean conjunctions. During the initial screening process, the authors examined the titles, abstracts, and Medical Subject Headings (MeSH) of the identified articles in PubMed. To expand the search coverage, the same search strategy was applied to the EBSCO databases, including MEDLINE and SPORTDiscus, followed by a review of titles and abstracts to identify relevant articles for further evaluation. Each citation obtained from the electronic bibliographic database underwent screening based on the eligibility criteria, leading to a decision to either include or exclude it from the study. We excluded papers that were: reviews, written in a language other than the English language, published before the year 2000, if the full text was not available, considered adults (outside of the age range of 8-19 years old), if the sample included participants with a shoulder or elbow pain or injury, or the samples included youth with physical and/or cognitive impairment (e.g., autism, cerebral palsy).

During the second level of review, the authors reviewed the full text of studies to establish their eligibility using the same criteria.

	Key Concepts	Search Strategy/ Phrase
Concept 1	Upper extremity injury prevention	**PubMed**: ((child[Title/Abstract]) OR

	programs in children and adolescent athletes	(children[Title/Abstract])) OR (kid[Title/Abstract])) OR (kids[Title/Abstract])) OR (adolescent[Title/Abstract])) OR (adolescents[Title/Abstract])) OR (adolescent athletes[MeSH Major Topic])) OR (youth[Title/Abstract])) OR (young[Title/Abstract]))) OR (youth sports[MeSH Major Topic])) AND (overhead[Title/Abstract])) OR (throwing[Title/Abstract])) OR (thrower[Title/Abstract])) OR (throwers[Title/Abstract])) OR (throw[Title/Abstract])) OR (pitching[Title/Abstract])) OR (pitcher[Title/Abstract])) OR (pitchers[Title/Abstract])) OR (pitch[Title/Abstract])) AND (upper (injuries[Title/Abstract])) AND (prevention[Title/Abstract])) OR (preventative[Title/Abstract])) AND (program[Title/Abstract])) OR OR (guidelines[Title/Abstract])) OR (recommendation[Title/Abstract])) OR (recommendations[Title/Abstract])) AND (biomechanics[Title/Abstract])) OR (biomechanical[Title/Abstract])) OR (kinetic[Title/Abstract])) OR (kinematic[Title/Abstract])) OR (kinetic chain[Title/Abstract])) OR (proper technique[MeSH Major Topic])) OR (body position[MeSH Major (programs[Title/Abstract])) OR (programme[Title/Abstract])) OR (programmes[Title/Abstract])) OR (strategy[Title/Abstract])) OR (strategies[Title/Abstract])) OR (guideline[Title/Abstract])) extremity[Title/Abstract])) OR (shoulder[Title/Abstract])) OR (elbow[Title/Abstract])) OR (arm[Title/Abstract])) OR (upper extremity[MeSH Major Topic])) AND (injury[Title/Abstract])) OR Topic])) OR (movement quality[MeSH Major Topic]) **EBSCO (MEDLINE and SPORTDiscus:** (child* OR kid* OR adolescent* OR youth OR young) AND (((injur* AND prevent* AND program*) OR (injur* AND

		prevent* AND strateg*) AND (("upper extremity" OR shoulder* OR elbow* or arm*) OR (throw OR pitch OR overhead) AND (biomechanic* OR kinetic* OR kinematic*)
Concept 2	Process-oriented physical competence assessment tools	**PubMed:** (((((((((((((((process-based[Title/Abstract]) OR (process-oriented[Title/Abstract])) AND (motor[Title/Abstract])) OR (movement[Title/Abstract])) AND (skill[Title/Abstract])) OR (competence[Title/Abstract])) OR (proficiency[Title/Abstract])) OR (capacity[Title/Abstract])) OR (physical competence[Title/Abstract])) OR (physical competence[MeSH Major Topic])) AND (assessment[Title/Abstract])) OR (assessments[Title/Abstract])) AND (throwing[Title/Abstract])) OR (throw[Title/Abstract])) OR (overhead[Title/Abstract])) OR (object manipulation[Title/Abstract])) AND (throwing skill) **EBSCO (MEDLINE and SPORTDiscuc):** (“process based” OR process-based) OR (“process oriented” OR process-oriented) AND ((physical* OR motor* OR movement*) AND (competen* OR skill* OR capacity* OR capability* OR proficien*) AND (throw AND skill*) OR ("object manipulation") AND (technique* OR “body position”) OR (*movement AND quality)

Table 1. Search Strategy

2.2.2 Data Collection and Extraction

The screening process of the study followed the PRISMA 2020 recommendations (Appendix A). After eliminating duplicate articles, we excluded the articles that were not eligible based on the exclusion criteria. Background information including the title of the study, author names, date of publication, the age range of participants, and interventions provided were extracted (Table 2). Formal risk of bias was not performed due to the variability in the types of studies and reviews examined in this scoping review. Appendix B shows the PRISMA checklist extension for scoping reviews.

2.3 Results

Fourteen studies were eligible and included for a scoping literature review (Table 2), among which nine were upper extremity injury prevention programs (Asker et al., 2022; Chalmers et al., 2017; Christoffer et al., 2019; Cobanoglu et al., 2021; Fredriksen et al., 2020; Østerås et al., 2015; Sakata et al., 2018a, 2019; Shitara et al., 2017; Sommervold & Østerås, 2017; Zarei et al., 2021) and five were process-based physical competence assessment tools (Barnett et al., 2009; Issartel et al., 2017; Lander, Morgan, Salmon, & Barnett, 2017; Longmuir et al., 2017; Tidén et al., 2015).

Injury Prevention Programs

We categorised upper extremity injury prevention programs into three distinct types based on their focus: specific exercises and assessments (Table 2), guidelines for restricting training volume (Figure 1 & 2), and instructional feedback to modify technique (Table 4). We chose these categories because they were the most common topics in the literature and provide a comprehensive framework for understanding and implementing effective upper extremity injury prevention programs.

Regarding exercise-based programs, we found only two studies that directly reported the effectiveness of the program in reducing injury rates in children (Sakata et al., 2018a, 2019), and one study in adolescent athletes (Asker et al., 2022). Other exercise-based studies reported the effectiveness of prevention programs on specific musculoskeletal risk factors, including strength and flexibility deficits (Cobanoglu et al., 2021; Fredriksen et al., 2020; Østerås et al., 2015; Shitara et al., 2017; Sommervold & Østerås, 2017; Zarei et al., 2021). Overall, targeted risk factors were deficits in shoulder muscular strength, shoulder joint range of motion, shoulder stability and dynamic balance, elbow range of motion, hip range of motion, and lower extremity balance. Full characteristics of exercise-based injury prevention programs suggested for adolescent throwing athletes to prevent shoulder and/ or elbow injuries are demonstrated in Table 2. Nine studies were found specific to upper extremity injury prevention program. Six focused on shoulder injuries (Asker et al., 2022; Cobanoglu et al., 2021; Fredriksen et al., 2020; Østerås et al., 2015; Sommervold & Østerås, 2017; Zarei et al., 2021), one focused on elbow injuries (Sakata et al., 2018b), and two on both shoulder and elbow injuries (Sakata et al., 2019; Shitara et al., 2017). Among the included studies, two focused on children aged 8-12 (Sakata et al., 2018a, 2019), and seven targeted adolescents aged 13-19 (Asker et al., 2022; Cobanoglu et al., 2021; Fredriksen et al., 2020; Østerås et al., 2015; Shitara et al., 2017; Sommervold & Østerås, 2017; Zarei et al., 2021). The sample populations comprised two studies involving males (Shitara et al., 2017; Zarei et al., 2021), two involving females (Østerås et al., 2015; Sommervold & Østerås, 2017), and five involving both sexes (Asker et al., 2022; Cobanoglu et al., 2021; Fredriksen et al., 2020; Sakata et al., 2018b, 2019). The sports investigated in the studies included handball (four studies) (Cobanoglu et al., 2021; Fredriksen et al., 2020; Østerås et al., 2015; Sommervold & Østerås, 2017), baseball (three studies) (Sakata et al., 2018a, 2019; Shitara et al., 2017), volleyball (one study) (Zarei et al., 2021), and a mixed group of throwers including javelin, shotput, and discus (one study) (Cobanoglu et al., 2021). There were five Randomized Controlled Trials (Asker et al., 2022; Fredriksen et al., 2020; Østerås et al., 2015; Sakata et al., 2019; Sommervold & Østerås, 2017; Zarei et al., 2021), two cohort studies (Sakata et al., 2018b; Shitara et al., 2017), one pilot study (Cobanoglu et al., 2021), one observational study (Barnett et al., 2009), and four validation studies (Issartel et al., 2017; Lander, Morgan, Salmon, Logan, et al., 2017; Longmuir et al., 2017; Tidén et al., 2015).

The studies collectively reflect a range of outcomes, demonstrating improvements in injury rates (Asker et al., 2022; Sakata et al., 2018b, 2019), range of motion (Cobanoglu et al., 2021; Sakata et al., 2018b, 2019; Shitara et al., 2017), strength (Østerås et al., 2015; Sakata et al., 2018b, 2019; Sommervold & Østerås, 2017), stability (Cobanoglu et al., 2021; Sakata et al., 2019; Zarei et al., 2021), and fundamental motor skills (Barnett et al., 2009; Issartel et al., 2017; Lander, Morgan, Salmon, Logan, et al., 2017; Longmuir et al., 2017; Tidén et al., 2015). Also, outcomes such as shoulder complaints (Asker et al., 2022; Østerås et al., 2015; Sommervold & Østerås, 2017), proprioception measurements (Zarei et al., 2021), and clinical assessments including ultrasonography and physical function outcomes (Sakata et al., 2019) were investigated. Studies might have applied different measurements for an outcome. For example, in the Østerås et al.'s study (Østerås et al., 2015), shoulder strength was quantified through the measurement of maximal repetition of push-ups, while in the Yokohama Baseball-9 studies (Sakata et al., 2018b, 2019), muscle strength assessments were incorporated as part of clinical evaluations. Furthermore, the same measurement could have been performed through different devices. For instance, to measure shoulder complaints as an outcome, both Østerås et al. (Østerås et al., 2015) and Asker et al. (Asker et al., 2022) used self-report questionnaires. Asker et al. (2022) used the Oslo Sports Trauma Research Center Overuse Injury Questionnaire, while Østerås et al. (2015) did not introduce the questionnaire they used in their study. Some studies pointed out limitations such as self-reported injuries and lack of blinding (Asker et al., 2022), highlighting areas for further research and refinement in these exercised-based injury prevention programs (Østerås et al., 2015).

Intervention	Study	design	Participants			Exercises/ Duration	Comparison	Measurements	Outcomes	Limitations
			Number	Age	Activity					
OSTRC **Shoulder** Injury Prevention Program	Østerås et al., (2014)	RTC*	F*: 109	16	Elite junior handball	-Push-ups plus the floor -Standing shoulder rotation inwards - Standing shoulder rotation outwards 6-month, 3-times/ week as a prolonged part of the general warm-up period of the training	-Training group (shoulder strength) vs control group (handball training only) -Pretest vs post-test	-Shoulder complaints: self-report questionnaire -Muscular strength in upper body: maximal repetition of push-ups	-Positive effects on shoulder complaints prevalence: Complaints in exercise group decreased from 34% in pretest to 11% in post-test. However, in control group increased from 23% to 36% (no differences regarding their field position) -Significant increase in shoulder-muscle strength: High significance in the increase in shoulder strength between the exercise and control groups (P<0.001), (measured by the number of push-ups)	-Low number of included players -Use of a retrospective questionnaire

	Sommer vold & Østerås, (2017)	RTC	F: 106	16	Elite junior handball	1) Push-ups with 1 minute break between the series, explosive performance, 0°–90° flexion of the elbows, elbows abducted 45° from the thorax. 2) Switching between “elbow-standing” and “hand-standing with extended elbows” 3 × 12 repetitions of high fatigue, 7-month 3-times/week	-Training/ control group -Pre-test/ post-test	**Functional tests**: -Push-ups repetition -Throwing distance -Shoulder IR and ER strength with a handheld dynamometer **Visual analogue scale:** Shoulder pain **Questionnaire** (Quick-DASH): Disability of the Arm, Shoulder and Hand	-No effect on prevention of shoulder pain, -No significant differences in between the groups	-No information about the players’ general characteristics (e.g., height, weight, weekly handball training, strength training)

	Fredriksen et al., (2020)	RTC	M*: 11, F: 46	16-18	Youth handball team	Five exercises aimed to increase ER strength, IR ROM, scapula stabilization, thoracic mobility, and kinetic chain involvement. 3-times/ week 18 weeks 15 min/ session	-Between group differences -From before until after 18 weeks of intervention	**Primary:** Manual muscle testing: -Shoulder ER isometric strength (handheld dynamometer) -Shoulder IR ROM **Secondary:** -IR strength, -ER/IR strength ratio -ER ROM, -Total ROM, -Glenohumeral internal rotation deficit (GIRD, the difference in IR between dominant and non-dominant arm) at 6, 12, and 18 weeks of intervention. -Isokinetic strength measurements of shoulder ER and IR strength	**Pre-/ post-test:** -Significant Increase in isometric ER strength in both groups (intervention:10%, control: 6%) -No change in mean IR ROM in either group **Between-group post-test**: -No significant differences in mean dominant shoulder isometric ER strength. -No significant differences for any of the secondary outcome variables	-Small sample size to compare male to female players -A possibility of contamination during simple randomization within the teams
	Cobanohlu et al., (2021)	Pilot	F: 4, M: 6	Mean 15.8	Adolescent throwers (discus, shot put, javelin)	3-times/ week during the warm-up period of training program	Pre-test/ post-test	-Glenohumeral ER and IR ROM by goniometer -Upper extremity functional performance through Closed Kinetic Chain Upper Extremity Stability Test (CKCUST)	-Significant difference in the dominant side IR ROM and CKCUEST	-Age range not included -Small sample size -Lack of control or comparison group

FIFA 11+S **Shoulder**	Zarei et al., (2021)	RTC	M: 32	Mean 17.49	Young elite volleyball players	FIFA 11+ as their warm-up protocol, 3-times/ week, 8-week	-Pre-test/ post-test -Intervention vs control group	**Proprioception measurement**: -Threshold to detect passive motion (TTDPM) -Joint position sense (JPS) Through Biodex System 4 dynamometer **Dynamic stability measurement:** The upper quarter Y Balance Test	-No significant differences in none of the proprioception variables (JPS and TTDPM) -Dynamic shoulder stability significantly increased post-test in the intervention group.	-Age range not included

Yokohama Baseball-9 (YKB-9) **Elbow**	Sakata et al., (2018)	Cohort	F: 18, M: 201	8-11	Youth baseball	**Stretch exercises:** (1) Brachial muscle massage, (2) Pronator muscle stretch, (3) Triceps muscle stretch, (4) Cross arm stretch, (5) Sleeper stretch, (6) Mobilization of the lower thorax, (7) Trunk rotation stretch, (8) Posterior hip stretch (9) Hip flexor stretch. **Strength exercises**: (1) Supraspinatus exercise, (2) Subscapularis exercise, (3) Teres minor exercise, (4) Trapezius exercise, (5) Push-up plus on elbow, (6) Upper back rounding exercise, (7) Trunk rotation exercise, (8) Lateral slide exercise, (9) Elbow to knee exercise. Performed during warm-up or at home, 1 or more times per week	-Clinical and ultrasonography assessments: baseline and at 3-month intervals over the 1-year follow-up. -Physical function outcomes: baseline and at the endpoint of the follow-up.	-Clinical assessment of the elbow and shoulder joint -Ultrasonography assessment of the elbow -Assessment of physical function (passive range of motion of the elbow, shoulder, and hip; strength of the shoulder and scapular muscles; and measurement of the thoracic kyphosis angle). -Shoulder IR ROM -Shoulder HR ROM -TSROM -Elbow extension passive ROM -Hip IR ROM -Lower trapezius muscle strength -Dominant limb strength -Thoracic kyphosis angle -Medial elbow pain with flexion, extension, and valgus stress -Tenderness on palpation of the proximal humeral epiphysis -Pain with resistance applied to shoulder IR and ER -Compliance	-Significantly lower incidence rate of medial elbow injury -Improved total range of shoulder rotation (dominant side), hip internal rotation (nondominant side), shoulder internal rotation deficit (bilaterally), lower trapezius muscle strength (dominant side), and the thoracic kyphosis angle. -Increased total shoulder rotation, increased hip internal rotation of the nondominant side, decreased thoracic kyphosis angle	-Participants were not randomized to the intervention and control groups -Risk of researcher bias due to lack of blinding the players to their group assignment during injury surveillance. -Not evaluating the mechanics of the pitching motion -Not monitoring the quality of the routine performed by individual players.

Modified Yokohama Baseball-9 (m YKB-9) **Shoulder** and **Elbow**	Sakata et al., (2019)	RTC	F: 18, M: 201	9-11	Youth baseball players	**Elbow ROM**: Massage of brachial muscles, stretch of pronator muscles **Shoulder ROM:** Posterior shoulder stretch, anterior shoulder stretch, **Hip ROM**: Posterior hip stretch, **Dynamic mobility of scapular and thoracic function**: Cat and dog exercise, trunk rotation exercise **Lower extremity balance training:** Lateral slide exercise, elbow-to-knee exercise 12-month	-Intervention/ control group -Baseline vs the end of the 12-month follow-up to evaluate the change in physical function	-Monitoring the incidence of shoulder and elbow injuries -Ball speed during pitching -Variables of physical function -Elbow passive ROM: Goniometer -Shoulder ROM: Goniometer and standard inclinometer -Hip ROM: Goniometer -Dynamic balance: Modified Star Excursion Balance Test -Thoracic kyphosis angle: Inclinometer	-Significantly reduced incidence of shoulder and elbow injuries. -Increased ball speed -Improved shoulder horizontal adduction deficits on the dominant side, hip internal rotation on the nondominant side, and the thoracic kyphosis angle.	-Lack of blinding -Lack of radiographic examinations -Inadequate sample size for secondary outcomes -Insufficient representation of girls -Lack of position-specific considerations -Need for larger studies and subgroup analyses

Shoulder and **Elbow**	Shitara et al., (2017)	Cohort	M: 92	15-17	High school baseball pitchers	**Exercises**: -Sleeper stretching exercise -Shoulder external rotation Once daily after baseball practice.	-Both stretching exercise and strength training (SM-group), -Only stretching exercise (S-group), -Only strength training (M-group), -Neither stretching exercise nor strength training (N-group)	-Injury occurrence (inability to play for ≥8 days because of shoulder/elbow symptoms). Log-rank test was used for between-group comparisons of survival distributions.	-The incidence of injury was significantly lower in the S-group than in the N-group -No significant difference in injury incidence between sleeper stretching and the combination of sleeper stretching and strength training	-Self-selection bias -Sample selection bias -Lack of information on time course of changes in ROM/ shoulder strength throughout season

Shoulder	Asker et al., (2022)	RTC	Shoulder group (M and F): 199 Control group (M and F):	15-19	Adolescent elite handball	Five principal exercises, each with four levels of difficulty, additional partner exercise, a throwing program To be performed during the of-season and pre-season consisting of four steps of progression in throwing velocity and number of throws. 12-month, of-season and pre-season: 3 times/ week with three sets of 15–30 s /exercise, Handball season: 3 times/ week with two sets of 15–30 s /exercise	-Pre- /post- test -Intervention vs control Intervention group: perform the program, Control Group: train and play as usual, received no trial intervention	Shoulder injuries defined by the Oslo Sports Trauma Research Center Overuse Injury Questionnaire	• **Primary outcomes** -Shoulder injury rate • **Secondary outcomes** -Time-loss shoulder injury -Substantial shoulder problems -Any shoulder problem -Weekly prevalence of substantial shoulder problems -Weekly prevalence of any shoulder problems	-Self-reported injuries -Limited injury classification -Composite severity score -Underpowered for subgroup analyses -Lack of blinding -Risk of confounding -Lack of previous research on certain factors
Canadian Agility and Movement Skill Assessment (CAMSA)	Longmuir et al., (2017)	Method Validation with Descriptive and Reliability Analysis	F: 526, M: 469	8-12	local schools and day camps (Ottawa)	Two-footed jump through yellow, blue, and red hoops. Slide sideways from cone 1 to cone 2 and back to cone 1. Catch ball thrown by examiner and then throw it al wall target Run from hoops to kick the soccer ball	---	Validity, objectivity, and reliability evidence for children 8–12 years of age	Validation of the CAMSA through expert consensus, associations with age and gender, and assessment of objectivity and reliability	No specific comparator mentioned

CAMSA, against the Victorian FMS Assessment from Australia	Lander et al., (2017)	Cross-Validation and Reliability Study	F: 34	---	Australian Independent girls' school	---	The performance of the participants on the CAMSA with their performance on the Victorian FMS Assessment	CAMSA total score CAMSA time score CAMSA skill score Victorian FMS	Both were reliable and valid. CAMSA has the advantage of both process and product assessment, less time needed to administer and higher authenticity,	Did not specify age range (mean age: 12.6), Only female participants
Get Skilled Get Active Assessment	Barnette et al., (2009)	Observational study	----	8-12	Australian High school student	Vertical jump, kick, hop, catch, overhand throw, side gallop	Not applicable, as there might not be a direct comparison group	Interrater objectivity for field-based fundamental motor skill assessment	Substantial interrater agreement (weighted kappa coefficient κ = .70)	Female and male participants are not reported separately
NyTid (Nyberg & Tiden) Assessment	Tidén et al., (2015)	Instrument development & validation	F: 627, M: 633	12-16	Swedish compulsory school pupils	Hand walk, swing on a rope, skin the cat, building a roof, forward roll, cartwheel, handstand, stationary throw, throw with run-up, dribble course, hops and jumps, walking the beam, rope skipping, sideways jump, sideways roll, crawling, underhand throw	Not applicable (as there's no direct comparison group)	Development and initial validation of the NyTid test: A movement assessment tool for compulsory school pupils	Confirmation of the NyTid test's validity as a process-oriented assessment tool for movement skills.	Potential complexity of movement skills leading to double loadings, limited internal consistency for some factors due to a small number of skills, and the need for further research on skill refinement and replacement

Test of Gross Motor Skills Development Second Edition (TGMD-2)	Issartel et al., (2017)	Cross-Validation	F: 388, M: 456	---	Local high schools		Not specified	Validity and reliability of an extended version of TGMD-, including the scores/ outcomes obtained from the TGMD-2 test (assessing 12 fundamental movement skills). These skills are evaluated based on specific critical features for each skill, and the outcomes are likely reported as scores indicating the proficiency level of the participants in these skills.	Good fit for evaluating adolescent proficiency in fundamental movement skills, offering a valid assessment tool for this age group	Did not specify age range (mean age: 12)

Table 2. Exercised-Based Injury Prevention Programs for Adolescent Throwing Athletes

RTC=Randomised Controlled Trial

F=Female

M=Male

ER= External Rotation

IR= Internal Rotation

ROM= Range of Motion

HR= Horizontal Adduction

TSROM= Total Shoulder Range of Motion

We did not find any volume-restricting program eligible for this scoping review. Although we found recommended guidelines to reduce the throwing volume, the effectiveness of these programs on reducing the risk of injury has not been investigated in the literature.

The American Sports Medicine Institute provides guidelines for weekly rest recommendations and maximum pitch counts based on the age of the athlete (Huckabee, Hannah, 2022). According to these recommendations, athletes aged 7-14 should adhere to specific rest periods based on the number of pitches thrown per week. For instance, those throwing 66 or more pitches require four calendar days of rest, while those throwing 1-20 pitches necessitate no rest days. Similarly, maximum pitch count recommendations vary by age group, with athletes aged 9-10 allotted 75 pitches per game and up to 2000 pitches per year (Huckabee, Hannah, 2022).

These guidelines serve as valuable resources for coaches, parents, and healthcare professionals involved in youth sports. Integrating such recommendations into training and competition protocols will facilitate prioritizing the long-term health and well-being of young athletes, minimizing the risk of overuse injuries associated with excessive throwing volume.

Throwing Biomechanics Injury Prevention Strategies

. Risk factors for shoulder and elbow overuse injuries were identified, including improper trunk rotational timing, which refers to the incorrect timing of trunk rotation during the throwing motion; desynchronization of trunk timing, indicating a lack of coordination between trunk movements and other body segments; and desynchronization of rotational timing between the pelvis and torso, highlighting a mismatch in the timing of rotational movements between these two body regions (Chalmers et al., 2017; Christoffer et al., 2019; Kraan et al., 2019). These factors have been associated with increased stress on the shoulder and elbow joints during throwing activities, potentially contributing to overuse injuries. For instance, when the biomechanics of the throwing motion are compromised due to improper trunk rotational timing, athletes may experience greater stress on specific joints, leading to conditions such as tendinitis, impingement, or ligament injuries. Addressing these issues through targeted interventions and corrective techniques is essential for injury prevention and the maintenance of optimal performance in athletes. Table 3 provides our findings on the different throwing phases, their associated body positions, throwing techniques, and identified risk factors in detail.

Throwing Phases	Body Position and Throwing Technique	Risk factors
Wind up	-This phase positions the body in preparation for force generation (Chalmers et al., 2017) -Hands brought together to the chest (Chalmers et al., 2017; Christoffer et al., 2019) -The knee of the lead leg lifted (Chalmers et al., 2017; Christoffer et al., 2019)	Improper trunk rotational timing (Chalmers et al., 2017)
Stride (early cocking)	-Initiates velocity generation through linear forward movement -Arm in the cocking position -The lag foot remains planted while the lead foot moves forward and down the mound, -Hip and knee extension. -Pelvis rotates to face home plate. -The lead leg extends while the pelvis rotates -Arm assumes the cocking position. -The back foot must remain planted during this phase	Improper trunk rotational timing Elbow flexion Desynchronization of trunk timing with stride and pelvic rotation (Chalmers et al., 2017).

Late cocking	-Front foot strike hand separation -The shoulder remains abducted 90° while externally rotating up to 180° through both the glenohumeral and scapulothoracic joints. -The torso rotates toward home plate	-Elbow valgus and rotational shoulder torque highest (Christoffer et al., 2019) -Pitching arm lagging behind the body before acceleration (Christoffer et al., 2019)
Acceleration	-The shoulder internally rotates -The elbow extends -The wrist flexes (Chalmers et al., 2017; Christoffer et al., 2019)	-Desynchronization of rotational timing between the pelvis and the torso (Christoffer et al., 2019) -Increased shoulder external rotation angle and joint force (Christoffer et al., 2019)
Deceleration and follow through	-The arm continues to internally rotate (although with decreasing angular velocity) -The rotator cuff muscles are activated to resist the forward movement of the arm (Christoffer et al., 2019) -Follow-though returns the body to a fielding position in preparation for the next play -The body assumes a relaxed position to allow for fielding of the baseball (Christoffer et al., 2019)	

Table 3. Instructions for Proper Throwing Biomechanics by Highlighting Kinetic Chain Deficits

Process-Oriented Assessment Tools

Among five included studies on process-based batteries, two of them targeted children (Barnett et al., 2009; Longmuir et al., 2017), and one study focused on adolescents (Tidén et al., 2015). The mean age of the participants across the rest was approximately 12 years old. Our analysis revealed overhead throwing assessment criteria that include transferring weight and rotating the body during the throw, maintaining focus on the target, standing side-on to the target, extending the throwing arm behind the body, stepping towards the target with the opposite foot, achieving sequential hip-to-shoulder rotation, and following through with the throwing arm down and across the body. The assessment criteria of each assessment tool are provided in Table 4.

Process-oriented Physical Competence Assessment Tool	**Assessment Criteria for Overhead Throwing**
Canadian Agility and Movement Skill Assessment (CAMSA)	- Transfers weight and rotates body when throwing. - Eyes are focused on the target throughout the throw. - Stand side-on to the target. - Throwing arm nearly straightened behind the body. - Step towards the target with foot opposite throwing arm during the throw. - Marked sequential hip-to-Shoulders rotation during the throw. - Throwing arm follows through and down across the body.
Get Skilled Get Active	- Eyes focused on the target area. - Stand side to the target. - Throwing arm in a downward and backward arc. - Step towards target area with foot opposite throwing arm. - Hips then shoulders rotate forwards. - Throwing arm follows through down & across the body.
Test of Gross Motor Development	- Windup is initiated with the downward movement of the hand/arm. - Preferred hand swings down and back reaching behind the trunk

	- Rotates hip and shoulders to a point where the nonthrowing side faces the wall. - Weight is transferred by stepping with the foot opposite the throwing hand toward the wall (not just transferring weight. Foot raised and lands). - Ball is tossed forward hitting the wall without a bounce - Follow-through beyond ball release diagonally across the body and down towards the non-preferred side. - Hand follows through after ball release to chest level
Motor Skills Protocol (CHAMSP)	- Wind-up initiated by downward movement of hand/arm. - Hip and shoulder rotated so that the nonthrowing side faces the target. - Steps (weight transferred) onto foot opposite throwing arm. - Differentiated trunk rotation. - Block trunk rotation. - Timing of release/flight of ball appropriate (late release = downward flight; early release = upward flight). - Arm follows through beyond release: down and across the body.
Preschooler Gross Motor Quality Scale	- Preferred foot, steps backward before throwing. - Arm, shoulder, and pelvis of the preferred side turn backward. - Hand over the head before throwing. - The center of gravity moves to the non-preferred foot after throwing. - Arm follows through to the opposite side after throwing.

Table 4. Process-Oriented Assessment Criteria

By comparing process-based assessments criteria and biomechanical instructions of throwing, we found similarities between the throwing-injury prevention strategies and the process-oriented physical competence assessment tools. Figure 3 illustrates the link between physical competence assessments and injury prevention programs. Table 5 shows this link through process-based assessment criteria for each throwing phase in detail, along with the specific pitching kinetic and kinematic flaws that should be evaluated to assess the quality and effectiveness of the throwing technique.

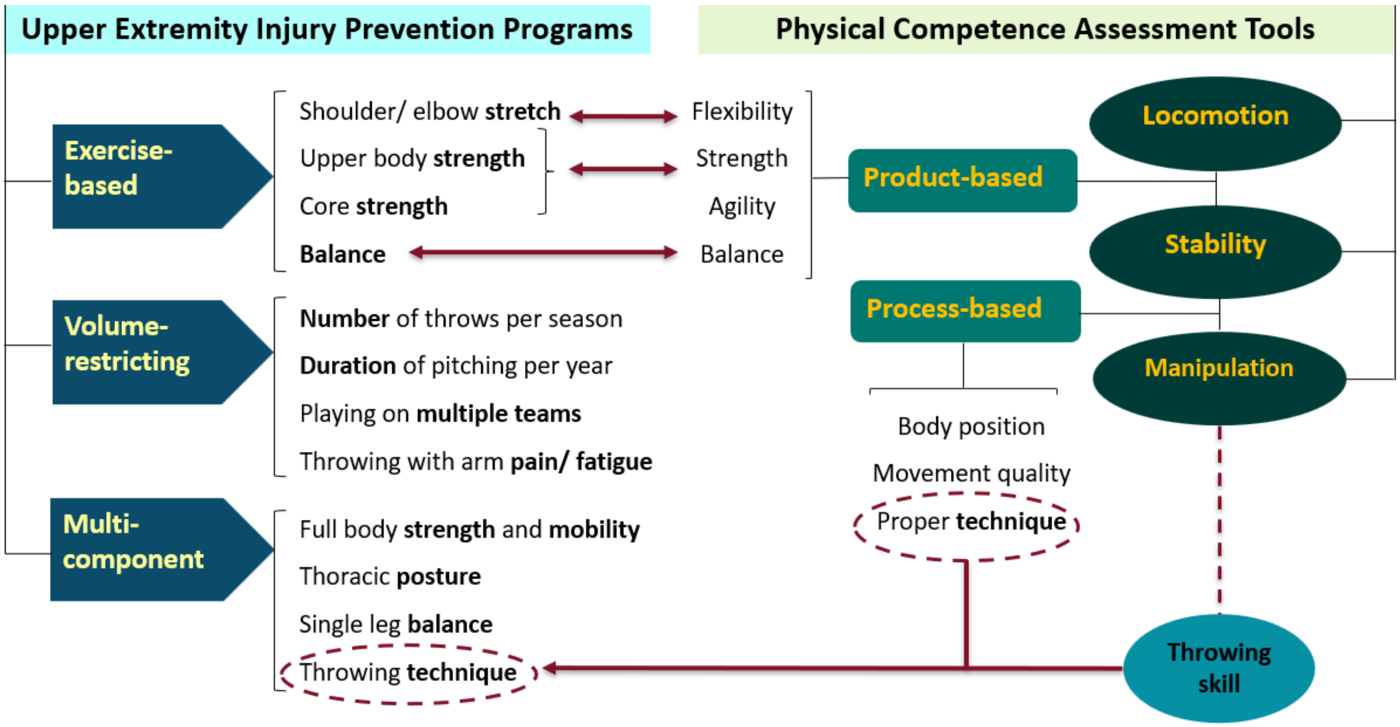

Figure 1. Links between injury prevention programs and physical competence assessments

In Table 5, we provide an overview of the similarity between characteristics of prevention strategies and process-based assessment tools, facilitating a comparative analysis of these key components. Additionally, we discuss how these similarities may influence the effectiveness of injury prevention efforts, highlighting potential links between specific features of strategies and assessment tools and their impact on reducing the risk of injuries.

Prevention Strategies based on throwing biomechanics	**Process-based Assessments Criteria for Throwing Skill**	**Risk Factors for Upper Extremity Injury**
Arm in stride position (Chalmers et al., 2017)	Arm swings down, back, and straightened behind. (Lander, Morgan, Salmon, & Barnett, 2017; Longmuir et al., 2017; Tidén et al., 2015)	Elbow flexion - increased valgus stress on the elbow, strain the ulnar collateral ligament (Chalmers et al., 2017; Christoffer et al., 2019)

Lead foot moves forward (Chalmers et al., 2017) Stride foot lands straight out from the back foot "on a line."(Christoffer et al., 2019)	Opposite foot to the throwing arm steps toward the target with the eyes focused on the target Stand side-on to the target (Issartel et al., 2017; Lander, Morgan, Salmon, & Barnett, 2017; Longmuir et al., 2017)	Large side step may affect vision (Chalmers et al., 2017)
Pelvis and torso rotate to face the home plate (Chalmers et al., 2017; Christoffer et al., 2019) Arm assumes the cocking position (Chalmers et al., 2017)	Marked sequential hip-to-Shoulders rotation (Issartel et al., 2017; Lander, Morgan, Salmon, & Barnett, 2017; Longmuir et al., 2017; Tidén et al., 2015) Hand over the head before throwing (Barnett et al., 2009; Tidén et al., 2015)	Desynchronization of rotational timing between pelvis & torso Arm lagging behind (Chalmers et al., 2017; Christoffer et al., 2019)
Arm continues to internally rotate (Christoffer et al., 2019)	Throwing arm follows diagonally across body(Barnett et al., 2009; Lander, Morgan, Salmon, & Barnett, 2017; Longmuir et al., 2017)	Poor balance point - may lead to compensatory movements, increased joint stress, and altered biomechanics, (Christoffer et al., 2019; Deal et al., 2020)
Hands brought together to chest (Christoffer et al., 2019)	Hand follows through to chest level (Barnett et al., 2009; Lander, Morgan, Salmon, & Barnett, 2017; Longmuir et al., 2017) Center of gravity moves to the non-preferred foot (Issartel et al., 2017; Lander, Morgan, Salmon, & Barnett, 2017)	Unstable center of gravity (Chalmers et al., 2017; Deal et al., 2020)

Table 5. Similarity between characteristics of prevention strategies and process-based assessment tools

2.4 Discussion

We conducted this scoping review to identify injury prevention strategies, examine the impact of these strategies, and to map them onto physical competence assessments. This section discusses the strengths, limitations, and gaps highlighted in this review and the broader literature related to upper extremity injury prevention and process-oriented physical competence assessments.

Injury Prevention Programs

Based on the findings of this scoping review, the available evidence regarding effective upper extremity injury prevention programs in adolescent throwing athletes is limited. We realized that the majority of studies focused on shoulder injury prevention, while only one study specifically addressed a program to prevent elbow injuries (Sakata et al., 2018a). It is worth noting that the incidence of elbow injuries in overhand throwers often occurs as a result of the biomechanical changes we make to our shoulder to adapt our body with the incorrect technique. These changes lead to excessive force on the elbow, by creating an altered technique (Mayes et al., 2022), suggesting interventions targeting the shoulder may indirectly address elbow injury prevention.

While upper extremity overuse injuries are well-documented in a variety of throwing sports, our scoping review revealed a notable emphasis on handball and baseball We found no research focusing on upper extremity injury prevention programs in sports such as tennis, golf, cricket, and badminton, despite reports of frequent injuries in these activities. This finding is aligned with the result reported by Wright et al. (2021) on shoulder injury prevention programs. Among seven studies in their systematic review two of them included handball and two other included baseball players (Wright et al., 2021). Four studies of seven were specific to adolescents. These results highlight the need for further investigation into injury prevention strategies in a broader range of throwing sports to address the specific needs of athletes in these disciplines.

In addition to limited evidence, we encountered conflicting results in injury prevention studies targeting similar populations with the same intervention. We found four studies investigating the effectiveness of the Oslo Sports Trauma Research Center (OSTRC) program in adolescent elite handball players. Among these studies, two reported positive outcome (decreasing injury risk factors) (Cobanoglu et al., 2021; Østerås et al., 2015), while the other two deemed it ineffective (Fredriksen et al., 2020; Sommervold & Østerås, 2017). Previously, a systematic review on shoulder injury prevention programs attributed conflicting outcomes to differences in study designs (Cools et al., 2021). Among our selected papers, same authors conducted a follow-up study two years later and reported different results (Sommervold & Østerås, 2017). This divergence may be attributed to changes in the measurement methods employed. The initial study utilized a questionnaire and a push-up test, while the subsequent study incorporated additional assessments, such as throwing distance, and used a handled dynamometer to measure shoulder internal and external rotation strength, all emphasizing a product-based approach. They also updated the previous questionnaire, which was a modified version of a Swedish questionnaire originally used for badminton players to identify shoulder complaints rate. They mentioned this fact as a limitation in their study since no previous trials investigated shoulder complaints in young handball players by using a similar questionnaire (Østerås et al., 2015). In the subsequent study, the Quick-DASH, which is an 11-item questionnaire designed to assess symptoms and physical function in individuals with upper limb disorders, was employed. The Quick-DASH was preferred since it has acceptable values for both reliability and validity. Lastly, they added use of the Visual Analogue Scale to screen for shoulder pain. Another factor contributing to conflicting results may be the varied outcomes measured across the studies. For instance, Sommervold et al. focused on isometric strength and pain complaints, Fredriksen assessed isometric and isokinetic strength, and range of motion, and Cobanoglu examined range of motion and kinetic chain. Despite the differences in the specific outcomes measured, the common thread in these studies was the investigation of factors related to physical performance and mechanics in the context of shoulder and elbow injuries. The ultimate goal in these studies was to identify risk factors or areas of deficiency that, when addressed, could potentially reduce the risk of injury or enhance performance.

A potential gap in the existing literature is the lack of consistency in implementing the injury prevention programs. Similar to our review, Huckabee and Hannah's (2022) review reported insufficient and non-cohesive data to determine the effectiveness of upper extremity injury prevention programs in adolescent baseball players (Huckabee, Hannah, 2022). They acknowledge that there is a theoretical recognition of the potential effectiveness of injury prevention programs for adolescent baseball players based on the understanding of biomechanics, injury mechanisms, However, they expressed concern about the current state of research in this area. They argued that there is a lack of sufficient and cohesive data from studies specifically focusing on the efficacy of upper extremity injury prevention programs in adolescent baseball players making it challenging to draw firm conclusions. Our review revealed a dearth of studies examining the effectiveness of non-exercise-based programs, such as pitch-count regulations (quantitative methods) and kinetic chain approaches (qualitative methods, but likely processed-based) in preventing upper extremity injuries in specific populations. While the concept of pitch-counts has been suggested as a preventive measure (Matsel et al., 2021), the evidence showing its efficacy remains minimal in well-designed studies.

Multicomponent injury prevention programs, encompassing comprehensive exercise regimens such as multicomponent neuromuscular training, have gained recognition for their potential in enhancing athlete performance and reducing injury risks (Jimenez-Garcia et al., 2022). These programs typically target various components, including strength, plyometrics, agility, balance, and flexibility, aiming to improve overall neuromuscular control and reduce the likelihood of injuries (Padua et al., 2018). One notable example is the FIFA 11+S program, initially designed to mitigate upper extremity injuries among soccer goalkeepers. This program integrates both technical and exercise-based approaches, focusing on neuromuscular control, core stability, eccentric rotator strength, and agility (Al Attar et al., 2021). While this study is not included in our collected data due to its broader age group focus, it underscores the significance of multifaceted injury prevention strategies.

Despite the age group limitations in our data collection, a noteworthy study by Zarei et al. (2021) explored the effects of the FIFA 11+S program specifically in young male volleyball players. Their findings revealed significant improvements in dynamic stability within the shoulders of these athletes, leading to enhanced overall performance (Zarei et al., 2021). This study contributes valuable insights into the potential applicability and benefits of multicomponent injury prevention programs in the context of youth athletes, reinforcing the importance of addressing neuromuscular control for upper extremity injury prevention.

In another eligible study, we noticed that authors focused on correct performance during stretching and strength exercises to improve shoulder external rotation strength in the preseason. Shitara et Al's prevention program included personalized one-on-one instruction sessions lasting 30 minutes, during which participants were guided in self-stretching exercises and strength training by an experienced physical therapist (Shitara et al., 2017). Additionally, participants received a brochure outlining the exercises with illustrations, written instructions, and guidance on avoiding compensatory movements (Shitara et al., 2017). The emphasis during these individual sessions was placed on ensuring correct execution of the exercises and preventing compensatory movements, thus promoting optimal movement quality, and reducing the risk of shoulder and elbow injuries among adolescent pitchers.

Multiple studies emphasized the significance of throwing biomechanics and kinetic chain for injury prevention, particularly in youth baseball (Chalmers et al., 2017; Christoffer et al., 2019; Luera et al., 2018; Oyama, 2012; Riff et al., 2016). However, no specific programs targeting these identified risk factors have been implemented to date. This gap in the literature suggests a need for future research to develop and evaluate intervention programs focused on improving throwing technique and its impact on upper extremity injury prevention.

While most of the literature focuses on the upper extremity, recent research has identified specific lower extremity deficits as independent risk factors for elbow pain and injury in throwing athletes (Deal et al., 2020; Hamano et al., 2021; Sekiguchi et al., 2017; Shitara et al., 2021). Deal et al. (2020) reviewed the role of the lower body in elbow injury in baseball players and concluded that elbow injuries are influenced by factors such as hip range of motion, lower extremity injury or pain, balance, and foot arch posture, illustrating a direct connection between these regions.

More recent studies confirmed the role of lower extremity deficits in upper extremity injuries for children and adolescent baseball players. Shitara et al. (2021) conducted a 12-month prospective cohort study on high school baseball players and found that limited ankle joint range of motion was a risk factor for shoulder and elbow injuries. Ankle mobility is crucial for proper weight transfer and force generation, two essential components of an effective throwing motion. Restrictions in ankle mobility may lead to compensatory movements and increased stress on the upper extremities, particularly the shoulder and elbow (Shitara et al., 2021). Also, Hamano et al. (2021) reported significant deficits in hip external rotation range of motion on the dominant side, hip internal rotation on the non-dominant side, and ankle plantar flexion on the non-dominant side in 8-12-year-old baseball pitchers with shoulder or elbow injuries compared to their non-injured peers. These deficits may lead to altered mechanics, increased stress on the shoulder and elbow, and potentially contribute to overuse injuries in young pitchers. These findings underscore the importance of considering lower extremity factors in comprehensive injury prevention programs for children and adolescent throwing athletes. The idea that lower extremity deficits contribute to upper extremity injuries aligns with existing literature on the importance of the kinetic chain in throwing sports (Chu et al., 2016; Ellenbecker & Aoki, 2020;

Mayes et al., 2022). Proper sequencing of movements from the lower body through the core to the upper body is particularly emphasized to reduce the strain on the arm (Bencke et al., 2018; Chalmers et al., 2017),Following these findings, Sakata et al. (2018 & 2019), and Asker et al. (2022) incorporated lower extremity balance training as a part of their upper extremity injury prevention program. Additionally, there was a study that considered hip range of motion and lower extremity balance in relation to elbow injury prevention in adolescents (Sakata et al., 2018a), but more study would enhance the knowledge in this area.

To put the existing knowledge into practice, future studies should focus on utilizing the findings from biomechanical analyses to develop instructional feedback programs and establish clear, systematized instructions. This approach will enable coaches, trainers, and other professionals to effectively teach proper throwing technique, modify improper techniques, and reduce the risk of upper extremity injuries in youth throwing athletes.

Physical Competence Assessment Tools

In this study, we aimed to review the literature to find possible (“a” or…) relationship(s) between physical competence and upper extremity injuries (Figure 4). We found that most shoulder and elbow injury prevention programs are exercise-based, focusing to improve strength, flexibility, and balance, which is aligned with the goals of the broad concept of physical competence.

Our finding on the connection between physical competence and injury prevention for children and adolescents can be supported by Zwolski et al.’s results. They reviewed the literature examining the role of strength in children and adolescents’ sports injury prevention. They suggested that the initiation of resistance training can accelerate the development of a functional foundation of strength, optimize performance and reduce injury risk during sport sampling in childhood and possible specialization after adolescence (Zwolski et al., 2017).

Product-oriented physical competence assessments of the throwing skill, such as distance or accuracy tasks, may not necessarily screen for upper extremity injuries in a direct manner. However, it is possible that certain performance indicators during product-oriented throwing tasks could be indicative of potential upper extremity injury risk. For example, if a child consistently throws with poor accuracy or limited distance, it may be a sign that they are experiencing pain or discomfort in their upper extremities (Sekiguchi et al., 2017). Similarly, if a child consistently throws with poor mechanics, it may be a sign that they are at risk of upper extremity injuries (Bencke et al., 2018)(Bencke et al., 2018). These findings are aligned with a recent systematic review on upper extremity performance in overhead youth athletes (Lau & Mukherjee, 2023). They reported that current upper extremity injury prevention programs seem effective at improving performance outcome measures with training components of strength, mobility and plyometrics (Lau & Mukherjee, 2023).

Process-oriented assessment of physical competence was of particular interest for our review, as it evaluates body position and proper technique. Miller et al. (2018) published a literature review with a similar attitude towards process-oriented assessments of locomotion and balance skills, connecting to lower extremity injury prevention programs, and in turn created a process-oriented assessment tool, called Child-Focused Injury Risk Screening Tool (ChildFIRST) (Miller et al., 2020). While process-oriented assessment tools like ChildFIRST have been developed for lower extremity injury risk screening, there is a lack of equivalent tools or strategies focused on assessing and preventing upper extremity injuries, particularly in the context of object manipulation skills. Similar to what Miller et al. reported for lower extremity injuries, our focus was to determine the presence or absence of a connection between process-oriented assessments and upper extremity injury prevention strategies.

Connecting Injury Prevention to Physical Competence

Based on our study, the overall object manipulation skills assessed by existing motor competence batteries include throwing, catching, striking, rolling, dribbling, and bouncing. With the exception of throwing, we did not find object manipulation skills in exercise-based upper extremity injury prevention programs. However, Miller et al. (2018) found the exercises included in lower extremity injury prevention programs were similar to locomotion and balance skills. Our research confirms that existing evidence of exercise interventions in overhead athletes is weak and dominated by exercises that do not reflect overhead athletes' sport-specific demands (Wright et al., 2021). While the programs did incorporate exercises that aimed to enhance overall strength, flexibility, and balance — targeting risk factors for overhead throwing athletes — they did not encompass the actual act of throwing. Highlighting the importance of body position and technique, it is reasonable to support evidence to connect upper extremity injury prevention to process-based assessments of the throwing skill (Figure 3). Table 5 shows the similar criteria, considered in both pitching biomechanics studies and process-based assessment tools for throwing. The throwing motion is a fundamental motor skill that is developed throughout both early and late stages of childhood (Oyama, 2012). Early on, children's throwing technique evolves from an arm-dominated movement to a more coordinated movement that includes trunk rotation, a forward step with the opposite leg, a back swing of the arm that will be used to throw, and horizontal arm adduction (Barnett et al., 2009; Stodden et al., 2006). Integrating the timeline of motor development in youth and adolescence, it is evident that the acquisition of mature fundamental movement patterns in late childhood (between 6 and 12 years of age) leads to the learning of sport-specific movement patterns. Subsequently, during adolescence (between 12 and 18 years of age) sports-specific motor patterns are further refined through frequent practice in sports settings (Stodden et al., 2006). In the realm of professional sports, it would be a mistake to believe that the technique used by elite professional baseball pitchers is always "proper" (Oyama, 2012). As the pitching movement becomes less variable and more automatic, making changes to the technique can pose challenges as it may disrupt the established automatic processes, potentially compromising performance (Oyama, 2012).

During assessments of the throwing skill, process-based tools use evaluation criteria such as “Step towards the target with foot opposite throwing” and “Arm follows through beyond release: down and across the body”, which result in the optimal body position required to perform a movement. Optimal body position involves a balanced and coordinated alignment of the feet, hips, and shoulders to generate power. Engaging the core, maintaining proper arm positioning, and ensuring sequential timing contribute to a controlled and accurate throw. Studies show that younger baseball players tend to sacrifice proper technique to achieve better speed and accuracy. (Christoffer et al., 2019; Luera et al., 2018; Riff et al., 2016). According to our results, evaluation of pitching technique should be based on presence of movement parameters that have been linked to excessive stress beyond the joint capacity, which is supported by research. Riff et al. reported that positioning with the hand under the ball in the early cocking phase, and lack of closed shoulder position at foot strike were commonly seen in younger pitchers, which places more stress on the medial elbow and shoulder (Riff et al., 2016) (Table 5). They also observed increased stride length, knee flexion at foot strike, and hip flexion at foot strike in the pitchers between 13-15 years old compared to those 9-12 years old (Riff et al., 2016). All of these factors collectively contribute to a decrease in the load imposed on the throwing arm (Christoffer et al., 2019; Riff et al., 2016). In another study, comparing professional and high school pitchers, high school pitchers did not demonstrate proper trunk and pelvis rotation, especially those throwing at higher velocities (Luera et al., 2018). Fleisig et al. (2018) reported significant changes in the kinematics and kinetics of youth pitchers, including a longer stride, improved foot position, and better trunk separation, when they compared different age groups from 9 to 13 years old.

Assessments of pitching mechanics may occur in high-tech laboratories to investigate kinetic factors such as elbow valgus torque, or a simple assessment of kinematic factors measured with video motion analysis (Chalmers et al., 2017; Davis et al., 2009). These assessments are used to estimate the risk of injury in individuals and are valuable in terms of injury prediction, but not necessarily prevention. Injury prevention requires a proactive approach, involving targeted interventions such as strength training, conditioning, and corrective exercises. While pitching mechanics assessments offer valuable insights into injury risk, preventive measures must be actively implemented to address identified issues and mitigate the risk factors revealed through such assessments. The most frequently identified factors include knee flexion at front foot contact, trunk rotational timing, shoulder rotation, and elbow flexion at ball release (Chalmers et al., 2017).

Our study establishes a link between physical competence and injury prevention, achieved by comparing the instructions in process-based assessments with the technique-focused injury prevention strategies for proper throwing technique We suggest future studies to use process-based physical competence assessment tools in creating a technique-based upper extremity injury prevention program, which is the priority for children and adolescent throwing athletes. In turn, the existing process-based assessment tools lack some criteria suggested by kinematic and kinetic studies to reduce the risk of injury. For example, Davis et al. identified five parameters, including " leading with the hips", "hand on-top position", "arm in throwing position elbow at max height at stride foot contact", "closed-shoulder position", and "stride foot toward home plate" to be evaluated on video analysis (Davis et al., 2009). These parameters can be added to future process-based assessment tools for the throwing skill.

In summary, the research gap in shoulder and elbow injury prevention for overhead athletes includes the lack of comprehensive programs that address proper technique. While the effectiveness of exercise-based programs has been extensively investigated, technique-based interventions have not been utilized to assess outcomes on children and adolescents. We determined that it is challenging to assess throwing technique objectively and reliably. The development of process-oriented physical competence assessment tools could be a solution. These tools would allow for evaluation of movement quality, enabling researchers and practitioners to identify and address faulty mechanics or inefficient movement patterns. By emphasizing proper technique and addressing the kinetic chain, these tools can help reduce the risk factors and minimize the likelihood of shoulder and elbow injury. It is important to acknowledge existing efforts in this direction. For instance, Davis et al. (2009) conducted a descriptive laboratory study analyzing biomechanical pitching parameters in youth and adolescent pitchers. Although not perfect, their work demonstrates an attempt to correlate correct pitching mechanics with lower humeral internal rotation torque, lower elbow valgus load, and higher pitching efficiency. While recognizing the contribution of such studies, additional research and refinement are needed to advance the development of more comprehensive and effective process-oriented assessment tools.

2.5 Conclusion

Upper extremity injury prevention programs, primarily targeting musculoskeletal risk factors such as shoulder strength and stretching, have shown effectiveness for reducing risk factors related to strength and range of motion. However, these programs may not achieve optimal injury reduction due to limited consideration of the multifactorial components indicated in throwing injuries in children and adolescent athletes. There is a need for additional studies that identify observable technical errors linked to heightened joint loading. These studies can contribute to the development of validated qualitative throwing evaluation tools, allowing for the screening of throwing athletes for injury risk and monitoring technique changes during field activities. Integrating process-oriented physical competence assessment tools into a comprehensive upper extremity injury prevention program can bridge the gap, providing a holistic approach to reducing youth athletic injuries.

Moreover, recognizing a specific need, there is an opportunity for the development and update of process-based tools tailored to throwing mechanics. For instance, incorporating knee flexion before throwing during the foot position phase could be emphasized. In this context, prospective physical competence assessment tools should prioritize the seamless integration of technique-oriented throwing biomechanical analyses within upper extremity injury prevention strategies.

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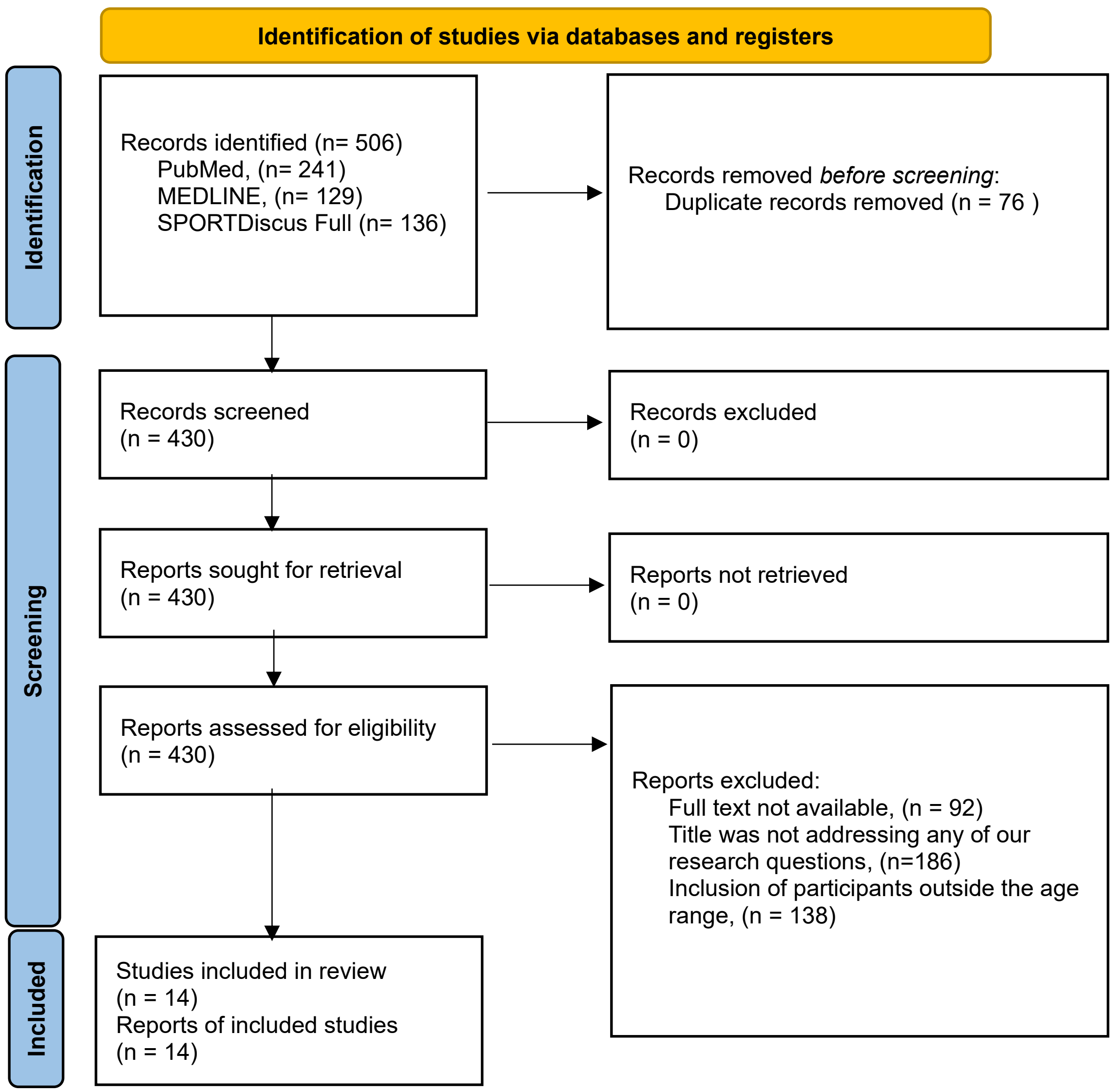
Appendixes

Appendix A – PRISMA 2020 FLOW DIAGRAM



Appendix B – PRISMA-SCR Checklist

Section & Topic	Item	Checklist item	Location
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	2-5
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	5
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	6
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	7
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	9-10
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	6-7
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	10
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	10
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	10
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	10
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	11
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	11
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	11-12
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	12-13
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	N/A
	13e	Describe any methods used to explore possible causes of heterogeneity among	12-13

		study results (e.g. subgroup analysis, meta-regression).	
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	10
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	N/A
Study characteristics	17	Cite each included study and present its characteristics.	10-21
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	N/A
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	11-21
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	11-21
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N/A
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N/A
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	11-21
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	N/A
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	28-38
	23b	Discuss any limitations of the evidence included in the review.	28-38
	23c	Discuss any limitations of the review processes used.	28-38
	23d	Discuss implications of the results for practice, policy, and future research.	28-38
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	N/A
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	N/A
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	N/A
Competing interests	26	Declare any competing interests of review authors.	N/A

Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	N/A