A SHOULDER INJURY PREVENTION PROGRAM IN YOUTH SWIMMING: 24-WEEK IN-SEASON TRAINING PROGRAM EFFECTIVENESS AND UNDERSTANDING OF PAIN AND INJURY PREVENTION AMONGST ATHLETES

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Chair of Committee: Daniel P. O'Connor, Ph.D.

Committee Member: Mitzi S. Laughlin, Ph.D.

Committee Member: Angela R. Tate, PT, Ph.D.

Committee Member: David W. Walsh, Ph.D.

Committee Member: Lane B. Bailey, PT, Ph.D.

University of Houston

by

Justin T. Reed, MS

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ABSTRACT

Shoulder pain and overuse injury are the primary physical ailments hindering the career of competitive swimmers. Currently the best injury prevention program to mitigate pain and injury has not been determined. Designing and implementing a pre-habilitation strength-training program based on the principles of rehabilitation could be an effective approach to this problem. The purpose of this study was to determine feasibility and impact of an in-season strength training and stretching program in adolescent, year-round, competitive swimmers. A total of 29 athletes were included for analysis; comparison group n=13, intervention group n=16. All intervention exercises were completed in a 30-minute period prior to the in-water training 3 days a week. Significant group by testing session strength differences were seen at mid-season for external rotation and internal rotation bilaterally, and on the left side only for horizontal abduction ($p<0.05$). Significant strength differences post-season were seen for internal rotation bilaterally, in the right arm for external rotation and left arm for horizontal abduction, ($p<0.05$). Additionally, this study surveyed a small sample (n=13) to determine their attitudes and beliefs about shoulder pain and injury prevention programs. Based on the survey data, it appears that previous history of pain and injury could change the way an athlete views swimming with pain. Additionally, it appears that the swimmers themselves would be receptive to implementing a shoulder injury prevention program, removing what is often perceived as a potential barrier to success. Together these results indicate that a shoulder injury prevention program is feasible and impactful for adolescent swimmers and that the swimmers themselves would be receptive to program implementation. Coaches should consider implementing evidence based injury prevention programs as a part of their dry-land training.

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INTRODUCTION

Study Rationale

Sport-related injury is the number one reason for emergency room visits in youth aged 12-17 years (Centers for Disease Control and Prevention [CDC], 2019). Many of these injuries are due to traumatic events with a relatively straightforward causal explanation for the injury. For overuse injury, such as the typical shoulder injury in swimming, it is more difficult to determine the causal factors that contribute to injury because there is usually not a single traumatic event. There is a need for better understanding of causes of injury to successfully implement interventions for injury prevention. However, assessing the cause of injury in sports can be difficult due to the frequent multiple contributors to a given injury (Meeuwisse, 1994).

Conceptual models for sport injury were developed originally to be similar to infectious disease models that stated, as an example, for disease to occur there must be an agent, a sustainable environment, and a host (Meeuwisse, 1994; Hulme, 2015). In non-traumatic sports injuries there is not usually a single factor (i.e., no analog to an infectious agent) that 'causes' injury, so much like current disease models, sport injury models became multifactorial (Meeuwisse, 1994). Meeuwisse (1994) described sport-related injury as the relationship between intrinsic factors, or characteristics within the individual that predispose an athlete to injury, and extrinsic factors, or conditions outside of the individual that are enabling factors or environmental factors, and an inciting event leading to injury (Meeuwisse, 1994). This multifactorial model was further developed to account for the dynamic relationships that the risk factors have with each other. Current models account for change in risk after the impact of a factor or event is encountered (Figure 1) (Meeuwisse, Tyreman, Hagel, & Emery, 2007).

While the core of the model (i.e., intrinsic factors, extrinsic factors, inciting event) has remained the same, recent modifications include how the risk factors relate to injury and how injury relates back to the risk factors. One key modification is that athletes can experience events that may not necessarily result in injury but still impact the athlete in some way. For example, an event could potentially cause an adaptation that affects the intrinsic or extrinsic risk factors and thus changes the predisposition and or susceptibility of the athlete to injury. A second important modification is accounting for recovery from injury and the potential to return to sport participation.

In practice, the model could explain overuse injury as follows. A non-injury loop wherein a swimmer begins training with a set predisposition to injury due to intrinsic factors and is exposed to a certain training regimen (extrinsic factors) during the season yet remains injury free, although not without adaptation. Exposure to heavy training loads and or an accelerated rate of loading could cause changes to intrinsic factors such as loss of flexibility and strength imbalances, among others. As the swimmer enters the loop again to start a new cycle of training after a cycle without an injury occurring, the predisposition has changed due to the changes and adaptations from the previous training cycle. This time, exposure to training may result in injury due to the compounding negative changes caused by the training exposure.

The model could also explain injury when predisposition does not change but the extrinsic factors change. For example, a swimmer begins a season in one training group that has a given level of training load and then advances into a more challenging training group with a much higher training load. In this scenario, the athlete has had no intrinsic change yet may became injured due to the extrinsic factors changing too drastically for his or her current level of predisposition, thus exceeding his or her ability to adapt to the new conditions.

This model can be used to help clinicians, coaches and athletes better understand the dynamics of sport-related injury risk in a variety of sport settings. Furthermore, this model can help understand etiology of injury by accounting for the changing circumstances in preceding sport participation even when injury did not occur (Meeuwisse et al., 2007).

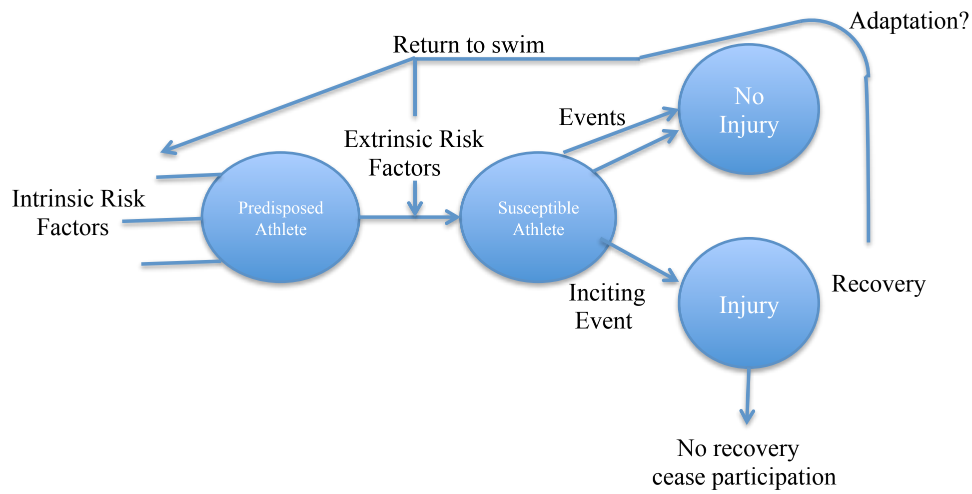


Figure 1: Theoretical model of injury adapted from Meeuwisse et al. (2007).

In competitive swimming, the shoulder is the most common reported area for pain and injury with a prevalence of 40% to 91% reported (Sein, 2010; Wanivenhaus, 2012; Bak, 2010). In a cross-sectional study of elite swimmers, Sein et al. (2010) found that 73/80 (91%) reported pain with 54% of those reporting unilateral pain while the remaining 37% reported bilateral pain. Many of the athletes reported that pain persisted in daily activity and the majority of them sought help but did not discontinue swimming due to their shoulder pain. In a 5-year prospective study of NCAA division 1 swimmers and divers, the majority of injuries reported were to the shoulder with 34.7% and 36.8% for males and females respectively, and the majority of injury incidence being reported as overuse injury (Kerr et al., 2015). Almeida, Hespanhol, and Lopes (2015) surveyed elite swimmers participating in a national swim meet for current pain and recent injury and found that 44.4% reported current shoulder pain and 46.5% reported a shoulder injury in the preceding 12 months. Shoulder pain in swimming is not a new problem, with research in the 1990's reporting that pain appears to become more prevalent with older ages and increased ability levels. McMaster and Troupe (1993) reported that 10% of 13-14 year olds, 13% of 15-16 year olds, and 26% of elite swimmers reported having current shoulder pain. When asked about any history of shoulder pain, the same groups reported a positive history in 47%, 66%, and 73%, respectively. The higher rates by age and ability levels could be due to the increase in total yardage and intensity as athletes transition from one training group to another, for which they are advanced both by age and ability. Despite the evidence of shoulder pain and injury being a problem, it can be difficult to quantify due to the varying definitions and reporting methods. Using a standardized definition for pain and injury could help provide clarity and help future attempts to research and mitigate shoulder pain and injury. In a 12-month prospective cohort study Walker, Gabbe, Wajswelner, Blanch and Bennel (2012) had 74 athletes aged 11-27 self-report shoulder pain and injury. Significant interfering pain (SIP) was defined as pain that caused cessation or modification of training, competition, or progression of training. Significant shoulder injury (SSI) was defined as any SIP episode that lasted two weeks or more. Using these definitions, Walker et al. (2012) found that 38% and 23% of athletes reported SIP and SSI respectively.

While shoulder injury is known to be a common problem in the sport of swimming, the underpinning mechanisms behind the causes of shoulder injury are not yet fully understood. Etiology of overuse injuries can be complex due to the relationship between intrinsic and extrinsic risk factors and the lack of a specific inciting event such as those seen in traumatic injury. A recent review identified a number of potential risk factors for shoulder injury, but due to insufficient evidence and poor study methodology none of them are considered to have a high level of confidence as causal factors (Hill, Collins, & Posthumus, 2015). In consideration of the theoretical model for sport injury, it is likely that no one risk factor alone causes injury. Due to the difficulty in assessing non-traumatic injuries, a critical look at the individual risk factors, both intrinsic and extrinsic, and how they could relate is required to better understand shoulder injury in swimming.

Previously identified intrinsic risk factors with a moderate level of confidence as contributors to injury that will be assessed in the present study include: clinical joint laxity and instability, internal/external rotation range of motion (IR/ER), previous pain and or injury, and competition level (Hill et al., 2015). Other intrinsic risk factors that have been previously identified as a low level of confidence that also will be examined in this study include: years of swimming experience, sex, IR/ER strength, and scapular strength (Hill et al., 2015).

Extrinsic risk factors that have been previously identified and will be further investigated in this study include training volume and intensity (Hill et al., 2015). Additionally, the investigation into athlete's attitudes and beliefs will include elements of the extrinsic factors related to shoulder injury such as the perceived coach's attitudes towards injury and the perceived peer views on shoulder injury as an expansion of the work done by Hibberd and Myers (2013). While this was not directly measured in their previous work, the authors concluded that the coach's role in the development of swimming culture should be further investigated. While this study will not directly investigate the attitudes and beliefs held by the coach(es), we will investigate what the athlete perceives these to be, which could impact the way the athlete responds to pain and or injury prevention. This will help elucidate the role that the socio-cultural environment, an extrinsic factor, plays in the prevalence rates for shoulder pain or injury.

Of these risk factors, some are modifiable and thus are of interest because they may provide ways to prevent injury. Intrinsic risk factors that are modifiable include joint range of motion, strength, and balance of motion and strength for the muscles in and around the shoulder girdle. Swim training results in postural changes due to repetitive movement patterns resulting in the overused muscles becoming stronger and shortened (i.e., less flexible, more resistant to lengthening) where as the underused muscles become proportionally weaker and more flexible (i.e., less resistant to lengthening). Specifically, the pectoralis minor length has been shown to be shorter in high school aged swimmers with pain compared to those without pain (Tate, Turner, Knab, Jorgensen, Strittmatter, & Michener, 2012). As postural changes worsen, the scapulae become increasingly protracted and subacromial joint space is reduced (Bak, 2010). These changes appear to be a result of high swimming volume and lack of a strength training program designed to maintain muscular balance (Bak, 2010).

Recent studies have attempted in-season interventions of 6-12 week periods to affect muscle strength of the shoulder girdle (Hibberd, 2010; Manske, Lewis Wolf, & Smith 2015). Hibberd and Meyers (2010) found evidence of strength improvements in collegiate swimmers over a six-week intervention period but suggested that the duration of the intervention may not have been long enough to cause clinically significant changes while the athletes continued their normal swim training. This six-week strength training and stretching intervention was also unable to alter scapular kinematics or subjective measures of satisfaction or function among study participants. Similarly, Manske et al. (2015) found that over 12 weeks of an in-season intervention for adolescent swimmers there was no statistically significant difference between the intervention and control group at six weeks. However, at 12 weeks, there was a statistically significant improvement in external rotation strength in the intervention group, as well as a higher percentage of strength gained for all other measures, although those increases were not statistically significant. Collectively, these results suggest that in-season interventions may need to be of longer duration to counter the effects of swim training on the athletes' bodies.

What athletes and coaches believe regarding injury and injury prevention programs also relates to both intrinsic and extrinsic risk factors related to shoulder injury in swimming. Intrinsically, an athlete with the attitude that pain is not normal while swimming would have a lower predisposition to injury than an athlete that felt pain while swimming was normal. As an extrinsic factor, a coach that addresses pain through stroke feedback, training modification, or injury prevention program implementation would theoretically be able to help reduce athlete susceptibility compared to coaches who do not or give the perception to their athlete that the pain is normal. An effective injury prevention program can only be successful if it is well received and properly executed by both the athletes involved and the coaches overseeing the training.

Currently only one study has investigated attitudes and beliefs of athletes in swimming. Hibberd and Myers (2013) reported that many athletes believe pain is normal and necessary to succeed. Previous studies in other sports have reported that athletes either do participate or are willing to participate in injury prevention programs if it can be shown that the program will reduce injury risk or injury rates (Martinez, 2016; Zech &Wellman, 2017). In a study of footballers, despite the athletes being partially aware of some intrinsic and extrinsic risk factors associated with injury, the injury prevention strategies implemented by the athletes were inconsistent with the current scientific recommendations (Zech & Wellman, 2017). Others have reported that coaches may not be fully aware of training volume recommendations to reduce injury risk for young athletes (Post et al., 2018). Additionally, Norcross, Johnson, Bovbjerg, Koester, and Hoffman (2015) reported that high school basketball and soccer coaches were unlikely to implement injury prevention program partially due to lack of understanding the advantages of such programs, believing that injuries are not a major problem, or perceiving barriers to implementation. The attitudes and beliefs of the coach as perceived by the athlete could also be a potential risk factor. For example, if a coach is not receptive to a complaint of pain, athletes may not report pain as often and continue training with pain. Understanding the perception of the attitudes and beliefs of coaches towards injury and or injury prevention is important since this could be a strong extrinsic factor related to the susceptibility of the athlete towards shoulder injury.

Statement of the Problem

Shoulder injury in swimming is highly prevalent and the best training approaches to avoid injury have not yet been identified. While rehabilitation of shoulder injury has been successful using specific exercises for improving strength and muscle balance of the scapulothroacic and glenohumeral joints, in-season prehabilitative training has not yet been able to establish best practices for an injury prevention program in competitive swimming (Bak, 2010; Cools, 2016; Hibberd, 2010; Manske, 2015; Reinold, 2009). When considering the injury model (Figure 1), it is important to recognize that shoulder injury is often treated by rest and physical therapy intervention with an eventual return to peak training. Addressing the strength and range of motion for competitive swimmers prior to injury could change their predisposition to injury as a prevention strategy. In a traditional strength training setting, 6-12 weeks of training would be expected to improve strength in untrained persons, yet the existing literature contains no convincing evidence of this effect in trained, competitive adolescent swimmers. No studies have investigated in-season training programs using an evidence-based exercise program to restore muscle balance and posture of swimmers over the entire 24-week duration of either of the two training seasons in competitive swimming in the United States, the short course, 25-yard season, or the long course, 50-meter season. Furthermore, research on the attitudes and beliefs of swimmers toward pain in swimming, which may be related to training practices that affect risk of injury, is limited (Hibberd & Myers, 2013), and no evidence for coaches' attitudes and beliefs, or the athletes' perception of them, has been published.

This study fills important gaps in knowledge concerning shoulder injury in competitive youth swimmers. First, this study investigates the effectiveness of an in-season injury prevention program in youth swimmers over the entire duration of the first 24-week portion of the competitive calendar for swimming in the United States, the short course, 25-yard training season. Additionally, this study further investigates the attitudes and beliefs of youth swimmers regarding shoulder injury and injury prevention programs. Finally, this study examines the athletes' perceptions of attitudes and beliefs of swim coaches towards injury and injury prevention programs.

Research Questions and Hypotheses

Research Question 1: Is an in-season evidence-based strength and flexibility training intervention feasible and impactful for competitive year-round youth swimmers?

Research Question 1.1: Will the intervention improve muscle strength and preserve range of motion over the 24-week period better than a comparison group doing coach implemented dry-land swim training?

***Hypothesis 1.1*:** The in-season strength training intervention will increase muscle strength better than the comparison group and preserve range of motion better than the comparison group over the 24-week intervention period.

The purpose of research question one is to determine the feasibility and to quantify the effect of an in-season injury prevention program in regards to changes in strength and range of motion over the course of a season. The aim is to show that the modifiable risk factors of muscle strength and range of motion can be positively changed while maintaining normal in-water training. Increasing strength and maintaining range of motion could positively change the athlete's predisposition to injury and reduce overall risk of injury. To have the desired impact for an intervention, it must also be evaluated for practical implementation, or feasibility. For an intervention to be feasible, it must be able to fit into the current schedule of training, be delivered consistently enough to elicit change, and be affordable for accessibility to swim teams. Understanding the feasibility and effectiveness of such a program can help influence training practices among youth swimmers in the future.

Research Question 2: What are the attitudes and beliefs among year-round competitive youth swimmers towards shoulder pain and injury prevention programs?

Research Question 2.2: How do year-round competitive youth swimmers perceive their coaches' attitudes and beliefs towards shoulder pain and injury prevention programs?

Research question two will help future researchers understand how athletes perceive shoulder injury and injury prevention programs as well as how they perceive their coaches' approachability for discussing injury and implementing injury prevention programs. Understanding what barriers exist or are perceived to exist from either coaches or athletes regarding injury prevention programs would help future efforts to design and implement such programs. These perceptions can be intrinsic to the athlete; for example, they may perceive an injury prevention program as beneficial for their performance (or not) or they may believe that such a program will reduce their risk of injury (or not). Barriers can also be extrinsic to the athlete based on their perception of their coaches' attitudes and beliefs. An athlete may not feel the coach's attitudes toward reporting pain or engaging in injury prevention activity are positive, therefore, creating a barrier to reporting pain or participating in a prevention program. Identifying attitudes and beliefs towards injury prevention programs could be essential in improving effective implementation of injury prevention programs.

Literature Review

Introduction.

This literature review provides a detailed overview of shoulder pain and injury in swimming. The primary aim of this proposed research project is to determine the feasibility and effectiveness of an in-season strength-training program in adolescent swimmers. Additionally, this project will explore the attitudes and beliefs of athletes regarding shoulder pain and their perception of attitudes and beliefs of their coach(es). To date, there is limited research regarding attitudes and beliefs in swimmers or coaches of swimmers. Due to the limited literature available, this review will focus on the background to the problem and include a review of post-injury interventions that have been successful for return to activity.

The review of the literature will contain overviews of the following: 1) swimmer's shoulder and posture, 2) swim training and mechanics concerning the shoulder, 3) a multifactorial model of sports injury, 4) shoulder function and dysfunction, 5) strength and range of motion as intrinsic risk factors for shoulder injury, 5) volume load and intensity as extrinsic risk factors for shoulder injury, and 6) attitudes and beliefs of athletes and coaches as intrinsic and extrinsic risk factors, respectively, for shoulder injury.

Swimmer's shoulder.

Swimmer's shoulder is a broad term that has been used since the 1970's to describe shoulder pain associated with swimming. Since then, many shoulder pathologies have been included under the term swimmer's shoulder such as impingement (various types), bursitis, scapular dyskinesis, tendonitis, and others. Generally, these pathologies are considered overuse injuries and could have a number factors leading to the injury. Bak (2010) suggested that the main factor is high training volume during growth in children and adolescents in the absence of a well-designed dryland training program. Becker (2011) suggested that male and female swimmers are likely to experience painful shoulder syndromes two and three times over their careers, respectively. For males the first occurrence is following the second growth spurt, while the second occurrence is in the high school to college transition (Becker, 2011). For females, the first occurrence is usually in adolescence when body weight increases but strength has not yet developed proportionately, at the same time that the athlete is likely to be moved into a higher training group (Becker, 2011). The second occurrence is typically in later high school, with the third occurrence in the transition from high school to college training (Becker, 2011). With both males and females likely to experience shoulder pain and injury in adolescence, it is important to examine the possibility of intervention to improve shoulder strength during these phases of weight gain and strength-to-weight ratio change.

Etiological factors for swimmer's shoulder have been previously summarized (Table 1). In addition to those items, shoulder range of motion, muscular strength, previous injury, attitudes and behaviors, and many others have been indicated as potential risk factors for shoulder injury (Hill, 2015; Struyf , 2017; Hibberd, 2013). However, with swimmer's shoulder covering such a broad spectrum of shoulder pathology, the specific etiology can be difficult to explain, which makes it difficult to create a prehabilitative intervention (Struyf, Tate, Kuppens, Feijen, & Michener, 2017). Despite these difficulties, there is general consensus that swimmer's shoulder develops due to the relationship between the exposure of the athlete to the repetitive movements and volume of training and the physical changes and or imbalances prior to or in adaptation to that exposure (Bak, 2010; Struyf, 2017).

One potential problem related to the development of swimmer's shoulder is postural adaptation of the athletes. Common alterations in muscular balance seen in shoulder pathologies can be seen in Table 2 (Dutton, 2012). Forward shoulder posture and the decrease in subacromial space are likely caused by an imbalance between the agonist-antagonist muscles of the shoulder due to the anterior muscles being used for propulsion in freestyle, backstroke and butterfly (Kluemper, Uhl, & Hazelrigg 2006).

Table 1. Etiology of swimmer's shoulder (adapted from Bak, 2010).

Etiology of swimmer's shoulder
Intrinsic Factors
Excessive laxity/general joint hypermobility
Isolated joint hyperlaxity
Posture, core stability and thoracic kyphosis
Scapular dyskinesis
Glenohumeral internal rotation deficit
Rotator cuff imbalance
Lack of flexibility/stiffness
Extrinsic Factors
Training volume-absolute or sudden increases
Technical errors
Hand paddles

Table 2. Muscle Imbalances common in Shoulder Pathology (adapted from Dutton, 2012)

Common Muscular Imbalances of the Shoulder Complex	
Muscles Prone to Tightness	Muscles Prone to Lengthening
Upper Trapezius Levator Scapulae Pectoralis Muscles Upper Cervical Extensors Sternocleidomastoid Scalenes Teres Major and Minor Subscapularis	Middle and Lower Trapezius Rhomboids Serratus Anterior Deep Neck Flexors Supraspinatus Infraspinatus

In a study of 39 high school and college swimmers Kluemper et al. (2006) reported that stretching the anterior agonists and strength training for the posterior antagonists had a significant reduction of relaxed forward shoulder posture. Hibberd et al. (2016) compared the physical characteristics of adolescent swimmers with adolescent non-overhead athletes and found that swimmers had minimal differences from non-overhead athletes in preseason. However, after 12 weeks of swim training, swimmers showed significantly increased forward shoulder posture and greater decreases in subacromial space compared to non-overhead athletes (Hibberd et al., 2016). These alterations over the course of training could predispose the athlete to shoulder pain and injury. Thus, interventions to mitigate postural changes associated with training could be an effective solution for in-season training of competitive swimmers (Kluemper et al., 2006).

Swim training biomechanics concerning the shoulder.

Swim training consists of four training strokes: freestyle or front crawl, backstroke or back crawl, butterfly, and breaststroke. Freestyle and backstroke are long axis strokes with body rotation around the center axis (axial plane rotation) while butterfly and breaststroke are short axis strokes with an undulating motion using hips as the fulcrum (Heinlein, 2010; Chorley, 2017). While there are 4 strokes used in competition and training, the majority of training time and distance is done using the freestyle stroke. Sein et al. (2010) reported an average 53% of practice time is spent swimming freestyle with a range of 25%-95%. This large volume of freestyle is something that may be seen in distance freestyle competitors, who also typically swim a higher volume in training than sprinters or middle distance swimmers.

Competitive events range from 50-1650 yards or 50-1500 meters for competitive club pool swimming. Training groups could be categorized by competition distance: sprint swimmers, those athletes whom primarily compete in events <200y/m; middle distance swimmers, athletes whom primarily compete in 200-500y/400m distance events; or distance swimmers who primarily compete in the 500y/400m-1650y/1500m distance events. The 500y, 800m, 1000y, 1500m and 1650y are all freestyle events, so these athletes spend a larger proportion of their training time in freestyle compared to the other groups who have another dominant stroke or are individual medley swimmers and must have proficiency in all 4 strokes to be competitive.

Freestyle.

The freestyle stoke consists of 3 primary phases, the pull, recovery, and glide, with the pull and recovery being broken down into early, mid, and late portions (Heinlein & Cosgarea, 2010). Conceptually, the stroke should be the same on the right and left side with both arms following the same movement pattern in an alternating fashion. The pull starts with the glide and reach followed by the early pull or the point where the swimmer anchors the hand and achieves the high elbow position where the elbow is higher than the hand and the swimmer pulls the body over the arm (mid-pull) using the shoulder as the fulcrum (Heinlein & Cosgarea, 2010). A summary of muscles activated for various phases of the freestyle stroke can be seen in Table 3.

Table 3. Muscle activations during each phase of the freestyle stroke adapted from Heinlein & Cosgarea (2010).

Early Recovery	Mid-Recovery	Late Recovery	Reach	Early Pull	Mid-Pull	Late Pull	End of Pull
Posterior Deltoid	Middle Deltoid	Middle Deltoid	Middle Deltoid	Pectoralis Major	Pectoralis Major	Latissimus Dorsi	Posterior Deltoid
Middle Deltoid	Upper Trapezius	Anterior Deltoid	Anterior Deltoid	Teres Minor	Serratus Anterior	Subscapularis	Middle Deltoid
Rhomboids	Serratus Anterior	Rhomboids	Upper Trapezius		Latissimus Dorsi		Supraspinatus
	Infraspinatus	Serratus Anterior	Rhomboids				
		Subscapularis					

Deviations from the normal stroke in the presence of pain included a wider hand entry, lower elbow position, early hand exit and altered muscle activation patterns (Heinlein & Cosgarea, 2010). Normal shoulder function for the pull phase should include scapular protraction, humeral adduction and internal rotation. Failure to achieve sufficient scapular protraction and insufficient body rotation are possible technical errors that can cause impingement (Chorley, Eccles, & Scurfield, 2017). Examples of other technique errors that contribute to shoulder impingement can be seen in Table 4 (Chorley et al., 2017).

Table 4: Technique flaws related to impingement, adapted from Chorley et al. (2017).

Problem	Technique Error	Solution
Increased Primary Anterior Impingement	Flat Shoulders	Rotate hips and trunk around the long axis of the spine
	Late breathing	Breath at hand exit
	Hand crossing the midline at entry	Rotate hips/trunk, avoid swinging during the recovery phase by keeping a high elbow
	Overreaching	Stretch from scapula and shoulder elevation not horizontal adduction

In a study of shoulder impingement, Yanai and Hay, (1998) found that the average duration of impingement during freestyle swimming was 24.8%ST (stroke time) in a group of 11 male college swimmers with 14.4%ST and 10.4%ST occurring in the pull phase and recovery phase respectively. They defined impingement by: 1) an internal rotation angle while swimming that exceeded the active internal rotation angle obtained for the combination of horizontal abduction and elevation while the arm was positioned above the shoulder height used for determining impingement during the pull or recovery phase; and 2) an elevation angle while swimming that exceeded the maximum active elevation angle used for determining impingement at or shortly after hand entry. However, the authors reported a large variability to the point that there were some stroke cycles with no impingement occurring and suggested that technique or physique could impact the amount of time an athlete spends in impingement per stroke cycle (Yanai & Hay, 1998). These results support the theory that shoulder pain and injury could be related to repetitive shoulder impingement (Yanai & Hay, 1998). With the majority of training being in freestyle, it is important for coaches and athletes to understand the technical errors that can contribute to occurrence of impingement.

Backstroke.

Backstroke, similar to freestyle, is the other long axis stroke. Like freestyle, the stroke should be the same on both sides of the body in an alternating fashion. The catch position is above the head with the pull phase including a body roll towards the submerged hand as the opposite hand recovers. Approximately mid-pull the recovering arm should be positioned at 90 degrees to the water surface, with the body being at its maximally rotated position. As the pull finishes and the recovering arm enters the water, the body returns to a flat (supine) position and the reciprocal pull phase begins. While there is no known research of impingement specifically during backstroke, timing of the arms, and entry position or body roll would place the shoulder in weaker positions that could result in pain or impingement similar to freestyle (Heinlein & Cosgarea, 2010).

Breaststroke.

Breaststroke involves a simultaneous pulling motion with the arms, a lunge forward and a powerful, propulsive kick. The pull portion of the stroke is more for assisting the upper body for breathing while the kick portion is the primary source of forward propulsion. The pull starts in the base streamline position with the arms stretched overhead, shoulder flexed and elbows extended (Heinlein & Cosgarea, 2010). After sweeping the hands out, the shoulders internally rotate and adduct as the body lifts to breathe followed by a forceful, lunge forward returning the body to the streamline position and recovery of the arms with the shoulders flexed with fully extended elbows prior to the powerful kick. Pain or injury in breaststroke could be caused by insufficient scapular upward rotation during recovery phase.

Butterfly.

Butterfly uses similar arm motions with similar muscle activity as freestyle, but the arms move simultaneously as opposed to the alternating use of the arms in freestyle. The pull phase of the stroke results in similar arm positioning as freestyle with the high elbow position being achieved as the elbows bend. As the pull phase continues, the shoulder moves to a 90 degree forward flexed position with hands slightly closer together pointing down creating a large surface area to pull the body through the water (Heinlein & Cosgarea, 2010). Pain or injury in butterfly could be due to wider hand entry, improper muscle activation, and scapular malpositioning (Heinlein & Cosgarea, 2010).

Multifactorial sports injury model.

Sports injury is no longer considered to be attributable to a single causal factor due to the recognition that many factors, both intrinsic and extrinsic, can change the predisposition and susceptibility of an athlete to become injured (Meeuwisse et al., 2007). Not only is injury multifactorial, the relationship between intrinsic and extrinsic factors is also dynamic. For example, scapular strength is an intrinsic risk factor related to maintaining stabilization and resistance to fatigue during training. As strength and resistance to fatigue improves, the risk of injury is reduced for the same training load.

This section of the literature review will discuss the specific intrinsic and extrinsic risk factors related to shoulder pain and injury in competitive swimming that are potentially modifiable through intervention. Intrinsic risk factors of interest include strength, range of motion, attitudes and beliefs of the athletes towards shoulder pain or injury and injury prevention programs. Extrinsic factors to be studied include load, volume and intensity of training as well as attitudes and beliefs of the coaches towards pain or injury and injury prevention programs.

Intrinsic factors for injury risk in competitive swimmers.

Intrinsic risk factors are those that predispose the athlete to injury. In consideration of the injury model, the predisposition of the athlete to injury could be mitigated through intervention to address various intrinsic risk factors. Potentially, as strength or range of motion changes, the risk changes either positively or negatively. As range of motion decreases due to training-induced muscle tightness, this could reduce the functional glenohumeral joint space and increase risk of injury, particularly during high volume or high intensity training. Conversely, improving or maintaining range of motion through a stretching intervention could maintain joint position during longer duration or higher intensity phases of training and reduce risk of injury. In addition, improving strength could help in dynamic stabilization and resistance to fatigue, particularly as training load increases during maturation, when the strength to weight ratio could diminish in adolescent athletes. To determine intrinsic risk factors for shoulder pain or injury, an understanding of normal scapular and glenohumeral function as well as alteration caused by swim training will help elucidate the potential role of strength and range of motion in swimmer's shoulder. The following section will cover: 1) shoulder function and dysfunction, 2) previous interventions for strength and range of motion in competitive swimmers and 3) rehabilitation of injured swimmers as a model for prehabilitation design.

Scapular function and dysfunction.

Swimming falls into the category of overhead sports due to the majority of the stroke movements involving arm elevation with the hand overhead while in a prone or supine position. Scapular control in overhead athletes is important because the shoulder girdle acts as a bridge to transfer power from the rest of the body into the arm, which, when control is impaired, can increase stress on the shoulder joint and potentially increase injury risk (Burn, McCulloch, Lintner, Liberman, & Harris, 2016). Normal arm elevation includes upward rotation and posterior tilting of the scapula and requires adequate shoulder joint internal and external rotation to avoid impingement and maintain stability to potentially avoid injury (Ludewig, 2009; Paine, 2013; Stone, 2018). In contrast, scapular dysfunction or dyskinesis is an alteration in normal scapular kinematics and can have numerous contributing factors (Paine & Voight, 2013). The serratus anterior and lower trapezius are important contributors to scapular upward rotation and are typically weak or inhibited with scapular dysfunction (Paine & Voight, 2013). Scapular dysfunction can result in a narrowing of the subacromial space or secondary impingement. Most shoulder pathologies can be traced back to impaired biomechanics and scapular muscle function (Paine & Voight, 2013).

Scapular dysfunction in overhead athletes and swimmers.

Recently in a systematic review, Burn et al., (2016) reported a prevalence of scapular dyskinesis of 61% in 1257 overhead athletes compared to 33% in 144 non-overhead athletes. In contrast, Standoli et al., 2018, reported only 56 (8.5%) of 694 asymptomatic elite swimmers demonstrated scapular dyskinesis at the National Youth Swimming Championships. The lower rate that has been reported for overhead athletes as a whole could represent a type of selection bias in that these athletes reached this level of competition, in part, because they had no problems with injury—the swimmers who became injured were unable to advance to elite level.

Hickey et al., 2018, conducted a systematic review and meta analysis investigating the increased chance of experiencing a pain event for asymptomatic athletes that had scapular dyskinesis compared to those who did not. Among the 419 athletes in the studies reviewed, athletes with scapular dyskinesis had a 43% greater risk of developing shoulder pain that those who did not have scapular dyskinesis, 56/160 compared to 65/259, respectively. DeMartino and Rodeo (2018) summarized the link between scapular protraction, a sign of scapular dyskinesis, and impingement as fatiguing of the serratus anterior and subscapularis leading to strain on the glenohumeral joint by the dominant pectoralis major, resulting in abnormal movement of the scapula, reduced subacromial space, and subsequent impingement.

In swimmers, the combination of repetitive movement patterns, high training volume, and lack of corrective dry land training could be a primary cause of pain and dysfunction (Bak, 2010). In a study by Su, Johnson, Gracely, and Karduna (2004), swimmers with impingement showed a decrease in scapular upward rotation after a single practice session compared to swimmers without impingement. Additionally, Bak, 2010, reported that a pain-free swimmer displays scapular dyskinesis and fatigue of scapular stabilizing muscles during a single training session but a strength training intervention prolonged the time to development of scapular dyskinesis. Therefore, the lack of scapular dyskinesis seen in the elite swimming group could have helped them reach the level at which they were competing by protecting them from the impingement seen when fatigue of scapular stabilizers and abnormal movement patterns begin. Development of an in-season training program that can increase the stability and resistance to fatigue of the shoulder girdle muscles could reduce the incidence of scapular dyskinesis and subsequent impingement, pain and injury.

Rehabilitation as a guide to prehabilitation programs in swimming.

While the best prehabilitative program is yet to be determined for competitive swimmers, successful treatment and rehabilitation of swimmer's shoulder has been demonstrated. Current recommendations for treating scapular dysfunction in general include focus on maintaining or restoring range of motion, strengthening of the core and glenohumeral and scapulothoracic muscles to maintain scapular stabilization and resistance to fatigue, which could help reduce risk of injury and muscle imbalances caused by sport specific movements (Cools, 2015; Paine, 2013; Shanley, 2013; Stone, 2018). Rehabilitation following shoulder injury focuses on reducing pain and inflammation, and strengthening, stretching, and improving the stability of the glenohumeral and scapulothoracic joints (Almeida et al., 2010). In a retrospective observational study, 14 swimmers with impingement responded well to nonoperative physiotherapy treatment with a mean return to swim time of 1.6 months (Butler, Funk, Mackenzie, & Herrington, 2015). In a case study, one swimmer was able to return to the pre-injury level of swimming after 8 weeks of manual therapy and strengthening of the core and scapular stabilizing muscles (Almeida et al., 2010).

Cools, Johansson, Borms, and Maenhout (2015) suggests that the main goals of a rehabilitation program for overhead athletes should be to restore flexibility particularly in the pectoralis minor, levator scapulae, rhomboids, and posterior shoulder structures. Additionally, the scapular muscles should be trained to improve agonist-antagonist strength balance and control of scapular motion. Exercises commonly used for rehabilitation of the shoulder complex can be seen in Table 5. Regularly performing these exercises prior to injury as a part of the development of youth swimmers could help maintain scapular stabilization, provide resistance to fatigue, or reduce risk of pain and injury. Paine and

Voight (2013) suggest that a scapular strength training program could be especially important in swimmers for scapular control and injury prevention. Rehabilitation exercises that will be the basis for exercise selection in the prehabilitation program used in the intervention group can be seen in Table 5, as summarized by Hibberd 2010 in a review of EMG activation during exercise. These exercises are important for restoring the muscular balance lost due to repetitive movement patterns in swim training. Particularly those muscles with very little activation, such as middle and lower trapezius, resulting in weakness and lengthening of the muscle as seen in Tables 2 and 3 (Dutton, 2012; Heinlein & Cosgarea, 2010).

Table 5. Summary of muscle activation measured by EMG for common shoulder exercises (adapted from Hibberd, 2010).

Exercise	**Muscles Activated**
Shoulder Extension	Latissimus Dorsi, Rhomboids, Subscapularis, Triceps, Teres Minor
Internal Rotation at 90	Lower Trapezius, Rhomboids, Serratus Anterior, Subscapularis, Teres Minor
External Rotation at 90	Lower Trapezius, Rhomboids, Serratus Anterior, Subscapularis, Supraspinatus, Teres Minor
Low Rows	Rhomboids, Subscapularis, Teres Minor
Scapular (Serratus) Punch	Rhomboids, Serratus Anterior, Subscapularis, Teres Minor
Y's	Lower Trapezius, Middle Trapezius, Serratus Anterior
T's	Infraspinatus, Middle Trapezius, Serratus Anterior, Teres Minor, Upper Trapezius

Interventions for strength or range of motion in swimming.

A strength-training program addressing the muscle imbalances caused by swimming is recommended to reduce the risk of injury. However, reports of implementing in-season strength-training interventions with the aim of addressing the problems believed to be associated with shoulder injury in healthy swimmers are limited. Manske et al. (2015) conducted a 12-week intervention with adolescent swimmers using exercise bands to strengthen shoulder flexion, extension, abduction, and internal and external rotation using randomly assigned intervention and comparison groups. While the intervention group did improve a greater percentage of strength, only external rotation was significantly different from the comparison group who only participated in normal swim training. A limitation to this study could be the limited exposure to the exercises. They describe a 2-3 times per week program consisting of 2 sets and 15 repetitions. According to the American College of Sports Medicine (2018), a frequency of ≥3 days/week with a repetition range of 8-15 reps per set is appropriate to increase muscle strength in this population. It could be that the sets and repetitions used combined with only having 2 days a week some of the time while 3 days a week other times might not be enough to overcome the negative impacts of the reported volumes to which adolescent swimmers are exposed on a daily basis.

Hibberd et al., (2010) evaluated a 6-week intervention in a group of 37 (18 male, 19 female) randomly assigned collegiate swimmers performing the intervention 3 days a week for 2 sets and 15 repetitions or 30 seconds, for strength training and stretching, respectively, to a comparison group performing normal training. While they did not find significant differences in strength between the groups, they did show that six weeks was enough to trend towards strength gains while the control group did not show similar trends. The Hibberd et al., (2010) intervention program showing minimal, but positive, changes in strength gives credibility to the idea that a longer duration of exposure to the intervention could have resulted in meaningful differences between the groups. In a 12-week in-season scapular training program, Van de Velde et al., (2011) compared a randomly assigned strength based training program (3 sets of 10 repetitions, higher resistance) to an endurance based training program (3 sets of 20 repetitions, lower resistance) in a group of 18 adolescent swimmers. Both groups performed the same four exercises that were focused on serratus anterior and trapezius muscles three days a week. The results show an overall increase in muscle strength for both groups over the 12-week period but no difference in peak force or fatigue index between groups. The results of Van de Velde, De Mey, Maenhout, Calders, and Cools (2011) further supports the possibility that a longer exposure to muscle training could have a greater impact in changing the strength of competitive swimmers who are exposed to large volumes of training on a daily basis.

Volume load as a risk factor in swimming.

Training load varies between teams, ability levels, and age groups, making it difficult to generalize load or volume in swimming. Generally, as an athlete increases in age or ability, the amount of time per training session and the number of training sessions per week will both increase, resulting in an overall increase in volume. Sein et al. (2010) reported a median of 40km/week (43,745 yards) but as many as 110km/week (120,297 yards), and similarly Hibberd and Meyers (2013) reported an estimated average of 42,000 to 48,000 yards/week based on a mode of 6,000-7,000 average yards during training and an average of 6.89 sessions/week. However, they also reported average training yards of up to 9,000 to 10,000 yards for some individuals. Hill et al. (2015) recently reviewed the available published evidence for effects of training volume and intensity on shoulder pain in competitive swimmers. Based on mixed results and quality of evidence in the current literature, the authors reported a low level of confidence for volume and intensity as risk factors for shoulder pain.

The relationship between volume and intensity as it relates to injury or pain has not yet been fully explored in swimming. A recent review reported that some studies indicate a higher incidence of injury with higher training volumes in a 12-month period, both higher total distances and higher number of hours, whereas other studies reported no association

(Hill et al., 2015). Competition level was identified as a moderate risk factor, with 3 of the 4 studies reviewed reporting more incidence of pain at the higher competition levels. The dynamic relationship between volume and intensity needs further investigation to better understand the relationship between shoulder pain or injury and these factors.

Athlete perspectives on pain and injury prevention programs.

In a survey of 102 swimmers training in the top club team level between the ages of 13-18, Hibberd and Myers (2013) reported that the belief that having moderate or severe pain was normal for swimmers was significantly related to swimming with moderate or severe shoulder pain, respectively. They also showed that most swimmers believed that having mild shoulder pain is normal, and 86% believed pain should be tolerated to complete the necessary yardage. Furthermore, 44% also believed a moderate amount of pain had to be tolerated during swim training. Pain medication was used by 72% of swimmers to continue practicing, with 47% of those using medication weekly. In total, Hibberd and Myers (2013) reported 44.4%, 55.1% and 12.9% swim through mild, moderate and severe pain, respectively, to complete the necessary yardage. These results indicate the prevailing attitude in these young swimmers was that swimming through pain is necessary and common to continue training. A further examination of attitudes and beliefs toward adopting injury prevention programs is warranted to further assess the feasibility of an in-season dry land training program designed to protect youth swimmers from injury.

Hibberd and Myers (2013) used the theory of reasoned action/planned behavior to assess the observed association of attitudes towards pain and the behavior of swimming with shoulder pain. The theory of planned behavior describes intention as the most important determinant for a person to perform, or not perform, a specific behavior (Figure 2). (Ajzen, 2005). There are three basic determinants in the theory that lead to intention: attitude toward the behavior, subjective norm, and perceived behavioral control. Attitude is the positive or negative view of performing the behavior. Subjective norm is the perception of social pressure to perform the behavior. Perceived behavioral control is the view of the person's ability to control the behavior (Ajzen, 2005).

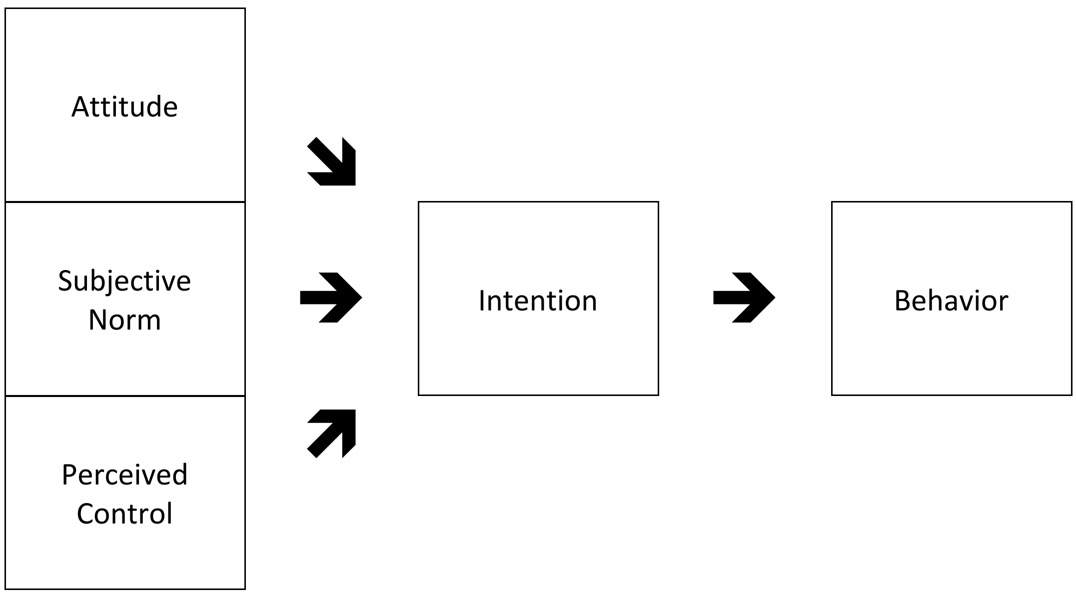


Figure 2. Adapted model of Theory of planned behavior for the current investigation.

Other theories have been widely studied and utilized in health or physical activity behavior change. Recently, Gabriel, McCann, and Hoch (2019) reviewed behavioral theories used in injury prevention research. Results showed that four theories were applied in 10 studies: the theory of planned behavior, the health-belief model, the self-determination theory, and the health-action process-approach model. All studies identified were used within exercise-related injury prevention program research at a level of high quality based on the criteria for inclusion in the review. Of the 10 studies, four used the theory of planned behavior and four used the health-belief model making these two behavioral models the most used for sport injury prevention research, while the theory of planned behavior is the most used (Gabriel, 2019; Keats, 2012). In youth sport, adherence to an injury prevention program may be influenced by attitude about individual risk for injury, priority such as the potential consequences of not adhering, and effectiveness of the program to actually reduce risk, as well as previous injury or social influence (Keats, Emery, and Finch, 2012). In this regard, the theory of planned behavior approaches behavior change by evaluating one's intention to engage in any activity based on their attitude towards the behavior, belief that others feel it is important (subjective norm), and their control or ability to perform the behavior (Keats et al., 2012).

Typically, competitive swimmers will participate in dry land training that progressively intensifies as they advance to higher levels of competition. Tate et al. (2015) reported that dry land training time increased progressively from 8 and under leagues to collegiate level swimmers in both minutes per day as well as total exposure per week (minutes/day*Days/week). Despite having the capacity to implement injury prevention programs, Tate et al. (2015) revealed that that dry land programs do not adhere to currently established best practices and recommendations. To identify the barriers in successful implementation of injury prevention programs requires determining coaches' and athletes' attitudes and beliefs towards such programs. Frank, Register-Mihalik, and Padua (2014) developed a survey to distribute among coaches assessing the behavioral determinants within the theory of planned behavior regarding anterior cruciate ligament injury. This survey was subsequently adapted to form the injury prevention program attitude survey, which assessed attitudes and beliefs among female adolescent soccer, volleyball and field hockey players (Martinez et al., 2016). Similar survey adaptation could be done for the swimming population to evaluate behavioral determinants regarding shoulder pain and injury.

METHOD

Research Question 1

Design.

This research project was implemented using a longitudinal, non-randomized study design with existing intervention and comparison groups, each being a local swim team. Within the structure of swim teams, athletes are placed into groups based on their age and ability to make homogenous training groups. The teams selected for this study were of similar size and ability level, and have similar training groups to match age and ability for the intervention and comparison groups.

All testing procedures were carried out over a twenty-four week period, with pre-season, mid-season and post-season testing being done at approximately twelve-week intervals. All testing procedures were conducted by licensed physical therapists employed at the Memorial Hermann Ironman Sports Institute.

Exercise intervention sessions were conducted with the intervention group three times per week between testing sessions as a part of the athletes' in-season training program. Exercise intervention sessions were monitored and progressed by a certified strength and conditioning specialist with ten years' experience working with swimmers specifically. The comparison group continued their normal dry land training program prescribed by their coaching staff.

Setting.

Two local swim teams in the Houston area participated, Swim Houston Aquatic Center, the intervention group, and Houston Cougars Aquatic Sports, the comparison group. All data collection and exercise intervention procedures took place at the respective team facilities to try and minimize missing data for the three data collection sessions over the 24-week intervention period.

Subjects.

Male and female swimmers ages 11-17 years participating in the year-round competitive swimming calendar were eligible for this study. This age range resulted in the enrollment of swimmers of a certain ability level. This ability group was selected because it usually represents a career phase prior to the swimmer beginning training involving multiple sessions per day, when the likelihood of injury increases. Additionally, the desired average age of participants was less than 15 years old due to the limited research in this population. Also, evidence of effective intervention and implementation could enhance adoption of prevention programs in this age group and have potential impacts on injury rates seen in the older population.

A total of 42 subjects were initially enrolled in this study, 21 for each group. A power analysis indicated to obtain 80% power, a sample size of 21 subjects per group would be needed, based on the effect size of 0.65, which represented statistically significant differences between measurements in pilot data from a similar repeated measures design with 14 subjects with no control group.

Subjects enrolled were fully participating in training and free of injury at the time of enrollment in the program. Exclusion for enrollment included: current shoulder pain reducing the ability to train normally, recovery from major injury within the past six months, previous surgery in the shoulder or elbow, any active systemic disease or illness, inability to maintain training requirements due to other injury or responsibilities, pregnancy (determined by screening questionnaire), or currently participating in a dry-land training program including the exercises used for the intervention. The swimmers maintained consistent attendance of no less than 70% of swimming and dryland training sessions prior to and during the intervention period, or they would be excluded from the study. Swimmers maintained the ability to perform the exercises used in the intervention and used an exercise log for the oversight of the training by the research team. Additionally, participants were able to understand and complete the study's intake questionnaire.

Recruitment of participant teams was done by contacting the head coach to explain the study purpose and procedures. After an agreement with the coach was established, the team members of the training group to be studied were addressed in a group meeting explaining the purpose and procedures involved with the study to parents and athletes. All consent and assent forms were provided as a part of this meeting and any questions were answered. For questions that parents or athletes did not wish to ask in public, email or phone contacts were given in order to ask them in private. Upon agreement to participate in the study the signed consent and assent forms were returned to the primary investigator for retention. Prior to the start of the study the University of Houston IRB approved all documents and procedures.

Intervention.

The research team had no influence over the programming chosen by the comparison group. The dry land training of the comparison group followed the usual program implemented by the club. This program, reported by the head coach, consisted of: overhead triceps extension, medicine-ball slams from overhead, burpees, push-ups, jumps, and pull-ups for repetitions as well as the following exercises 2-3 days a week, in certain training phases only, for time (:30 seconds) and in alternating motions with an elastic tube; punching, straight arm flexion and extension, straight arm abduction and adduction, internal and external rotation, latissimus pull overs and swim simulations mimicking the in-water technique. In order to participate in the study the comparison group could not be currently using the pre-habilitation exercises, following current recommendations provided by ACSM (2018) intended for this project regarding scapular or glenohumeral joint strength or range of motion.

The intervention program began in August at the start of the 25-yard, short course training season and continued through March at the conclusion of the short course season. This period is approximately 24-weeks and consisted of baseline testing in mid August to early September, mid-season testing in December and final testing in March. The groups were tested in the same order at each interval with the goal of having the test sessions separated by one week, i.e. comparison group followed by intervention group seven days later.

The intervention group performed the strength-training program three times a week for three sets and 8-15 repetitions for each exercise in the intervention program. This meets the current ACSM (2018) recommendations for children and adolescent resistance training of ≥3 days per week, with 8-15 repetitions of submaximal muscle strengthening with good mechanical form (ACSM, 2018). Stretching exercises were performed 2-3 times for 30 seconds each in compliance with the latest ACSM (2018) recommendations. When a swimmer in the intervention group missed a dry land exercise session, they were provided an opportunity to make up the session or take resistance bands home to complete the exercises. Exercises included in the intervention program and the respective muscle groups targeted can be seen in Table 6.

Table 6: Exercises to be performed by the intervention group

Exercise	Major Group(s) Targeted	Instructions and Progression
Rows with scapular retraction	Scapular retractors, Latissimus Dorsi	Standing facing a stable pole with the band wrapped around, the swimmer will start with a protracted scapula and extended elbow. Pulling straight back the swimmer will fully retract the scapula while flexing the elbow and then return to the starting position with control.
Horizontal abduction (T's)	Scapular retractors	Starting in a standing position with the shoulders flexed to 90^o, arms supinated and elbow fully extended holding the band in each hand the swimmer will horizontally abduct the shoulder to full scapular retraction and return to the starting position with control.
External Rotation (advance to 90° of abduction)	External rotators	Starting in a standing position with the arms by the side and elbow flexed to 90^o holding the band in each hand the swimmer will fully externally rotate the shoulder and return to the starting position. Advancement of this exercise will be to begin with the shoulder abducted and elbow flexed to 90^o in full internal rotation holding the band in each hand wrapped around a pole. The swimmer will then fully externally rotate the shoulder and return to the starting position with control.
Serratus Punch at 90° and 140° of forward elevation	Scapular upward rotators, Serratus Anterior	Standing with the band wrapped around the back at the level of the scapula, shoulder flexed to 90 and 140^o, scapula fully retracted, and holding the band in each hand the swimmer will maximally protract the scapula by 'punching' the arm forward and return to the starting position.
Y's (on a physioball or with bands)	Scapular upward rotators, Lower Trapezius	Starting in a kneeling position and leaning the torso against a physioball with the shoulder abducted to 135^o, elbow fully extended thumbs facing upward, the swimmer will lower the arm in a controlled manner toward the ground and raise it back to the starting position. Using a band, the swimmer will start standing holding the band in one hand against the hip with the other arm holding the band overhead with the elbow fully extended and the shoulder abducted to 135^o. The swimmer will lower the arm at an angle until approximately parallel to the ground and return to the starting position
Shoulder Extension	Scapular retractors	Standing facing a stable pole with the band wrapped around the swimmer will start with the band at the level of the hand palms facing forward shoulder slightly flexed and elbow fully extended. The swimmer will fully

		extend the shoulder and return to the starting position under control.
Planks	Core stabilization	The swimmer will hold the body up prone with the shoulder and elbow flexed to 90^o, toes and forearms only maintaining contact with the ground contracting the core musculature to maintain a straight line from the ankle to the shoulder.
Side Planks	Core stabilization	The swimmer will hold the body up on their side with the shoulder abducted to 90^o and elbow flexed to 90^o, foot and forearm only maintaining contact with the ground contracting the core musculature to maintain a straight line from the ankle to the shoulder and repeated for right and left sides.
Bird Dogs (quadruped)	Core stabilization	Starting in the quadruped position, arms/hands directly under the shoulder and knew directly under the hips with a neutral spine. The swimmer will move one arm to 180^o of flexion while extending the opposite leg to the neutral position while maintain a tight and stable core and hold the position. Once the swimmer has returned to the starting position the movement will be repeated with the opposite arm and leg.
Goal Post Stretch	Pectoralis Muscles	Lying supine on a foam roller over the spine with the shoulder abducted and elbow flexed to 90^o, the swimmer will attempt to get the forearm to contact the ground. Once the range of motion is such that getting to the ground no longer stretches the pectoralis muscles, the swimmer will stand with the arm in the same position with the forearm against a doorframe and rotate the torso to achieve the stretch.
Prayer Stretch	Latissimus Dorsi	Kneeling with maximum hip and knee flexion the swimmer will reach the arms as far forward as possible to make hand contact with the ground without hip or knee movement and press the torso towards the ground. Once the bilateral movement is no longer achieving a stretch the swimmer will unilaterally perform the movement rotating the torso in the opposite direction of the side being stretched.
Sleeper Stretch	Posterior Capsule	Lying on the side to be stretched, the swimmer starts with the shoulder and elbow flexed to 90^o. The shoulder is then internally rotated using the opposite arm and repeated on the opposite arm.

Outcome Measures.

Primary outcome measures included changes in strength and endurance of several motions (Table 7) and range of motion in several planes (Table 8) for the 24-week intervention period. Secondary outcomes for this project included changes in the subjective measures of shoulder pain and function as measured by the questionnaire.

For the primary outcomes, strength changes were measured as maximal isometric voluntary force production using a handheld dynamometer (Microfet 2 Hoggan Health Industries Inc. Draper, UT) using a “make” test (Table 7). Over a five second period, the athlete was instructed to gradually push harder and maintain their best effort while verbal encouragement was provided. All measurements were collected in duplicate; if differences between measurements of more than 3 Nm were obtained, a third measure was taken. All strength measures were averaged as the best two attempts within the 3 Nm range for analysis.

Range of motion was measured with a digital inclinometer (Baseline Digital Inclinometer, Baseline Evaluation Instruments). All range of motion measurements were collected in duplicate and a third measurement was taken if there was a difference of 5 degrees or more between measurements.

Table 7: Tests of muscle strength and endurance

Internal Rotation at 90^{o} of abduction
External Rotation at 90^{o} of abduction
Horizontal abduction
Shoulder elevation full can
Posterior shoulder endurance test (1-lb weight)

Strength testing for internal and external rotation.

The swimmer lay prone on the table with the shoulder abducted and elbow flexed to 90^o. Holding the handheld dynamometer at the wrist the examiner stabilizes the swimmer's arm and instructs the swimmer to push against the dynamometer as hard as possible to perform a make test of maximal voluntary isometric force. For external rotation the examiner holds the dynamometer on the back of the wrist while for internal rotation the dynamometer is held on the palm side of the wrist.

Strength testing for horizontal abduction.

The swimmer lay prone on the table with the shoulder abducted to 90^o, the elbow fully extended and the thumb facing up. Holding the handheld dynamometer at the wrist the examiner stabilizes the swimmer's arm and instructs the swimmer to push against them as hard as possible to perform a make test of maximal voluntary isometric force.

Strength testing for shoulder elevation "full can".

The swimmer sat on the table with the shoulder flexed to 90^o and approximately 30^o of abduction with the thumb facing up. Holding the handheld dynamometer at the wrist the examiner stabilizes the swimmer's arm and instructs the swimmer to push against them as hard as possible to perform a make test of maximal voluntary isometric force.

Posterior shoulder endurance test.

The swimmer lay prone on the table with the shoulder abducted to 135^o, the elbow fully extended and the thumb facing up. Holding a 1-lb weight, the swimmer maintained contact with a target, placing the weight against it as long as possible. Once the swimmer broke contact with the target they were given one verbal encouragement to maintain contact with the target. Upon the second separation from the target the test was terminated, and the time recorded.

Table 8: Range of motion measurements

Shoulder flexion in neutral
External Rotation at 90^o of abduction
Internal Rotation at 90^o of abduction
Meyers horizontal adduction

Shoulder range of motion testing for flexion.

With the swimmer supine on the table, knees bent, and back flat, the examiner passively raised the swimmer's arm into flexion overhead while the swimmer maintained lumbar spine contact with the table. At the point of first tissue resistance, the examiner recorded the range of motion.

Shoulder range of motion for internal and external rotation.

With the swimmer supine on the table, knees bent, back flat, shoulder abducted and elbow flexed to 90^o, and forearm perpendicular to the table, the examiner internally (palm toward the table) and externally (back of hand toward the table) rotated the shoulder until the point of first tissue resistance and recorded the range of motion. Scapular stabilization was maintained while a second examiner measured and recorded range of motion (Bailey, Shanley, Hawkins, Beattie, Fritz, Kwartowitz and Thigpen, 2015).

Meyer's horizontal adduction.

With the swimmer supine on the table, knees bent, back flat, with shoulder abducted and elbow flexed to 90^o and the scapula stabilized, the examiner adducted the humerus until the first point of tissue resistance and recorded the range of motion.

Special tests.

In addition to strength and range of motion, special tests of the shoulder that indicate impingement or laxity of the joint were conducted. These tests were performed to determine if the general shoulder health changes throughout the season. As has been previously described, the tightness and muscular imbalance that could develop over the season may impact the results of clinical tests for impingement or laxity of the glenohumeral joint. The special tests chosen for this proposed project were as follows:

Hawkins Kennedy (impingement): Passively flex the arm to 90^o in the scapular plane, stabilize the arm and force humeral internal rotation (Cook & Hedges 2013), with pain indicating a positive test.

Neer (impingement): Passively raise the arm into flexion while stabilizing the scapula. Apply forced flexion toward the end range of motion that reproduces shoulder pain indicates a positive test. (Cook & Hedges 2013).

Painful Arc (if the painful arc is positive then the scapular assistance test was performed to assess for scapular contribution to impingement): The athlete actively abducts the arm in a seated position, if painful (positive test), the athlete rated the pain on a scale of 1-10. The test was then repeated using the scapular assistance test with the tester pushing laterally and superiorly against the inferior medial border of the scapula (Kibler 1998). The athlete was again asked to rate their pain during the scapular assistance test. Decrease or elimination of pain with this maneuver is a positive test for scapular contribution to impingement.

Empty can (if the empty can is positive then the scapular reposition test was performed to assess for scapular contribution to impingement): The athlete elevated the arm to 90^o and horizontally adducts 30^o in the scapular plane with the thumbs pointed down. The examiner applied downward pressure, with pain indicating a positive test (Cook & Hedges 2013). If positive, the test was repeated using scapular reposition test (SRT) performed according to Tate, McClure, Kareha, & Irwin (2008). In brief, the examiner placed their hand over the shoulder with the palm on the scapula, fingers grasping the acromioclavicular joint, and forearm pressing on the scapula to provide support on the medial border of the scapula. Pain ratings were recorded for both the original test and the test using the SRT. A significant reduction or abolition of pain was considered a positive test.

Sulcus sign (instability): Placing the arm at 0^{o} of abduction and neutral rotation, the sulcus sign is considered positive if there is a greater than a fingerbreadth between the lateral acromion and humeral head when downward pressure is applied at the elbow.

90-90 apprehension (instability): With the athlete supine, the examiner positioned the shoulder in 90^{o} of abduction and externally rotated the humerus. Posterior to anterior pressure was applied to the posterior aspect of the humeral head (Cook & Hedges 2013). The athlete reacting by muscular guarding (apprehension) indicates a positive test.

Reduction/relocation (instability): If the 90-90 apprehension test is positive, the examiner then applied force posteriorly to the proximal humerus. A decrease of pain or apprehension indicates anterior instability and no change indicates impingement. (Cook & Hedges 2013).

Analysis plan.

Descriptive analyses were done for all variables to summarize distributional characteristics (e.g., central tendency, variability). Data for strength and range of motion outcome measures were analyzed using linear mixed models for repeated measures, using an unstructured covariance matrix and the Kenward-Roger approximation for small sample size, to determine differences between groups over time. Bonferonni adjusted post hoc t-tests were used to determine the location of the significant effects. Statistical significance was set at $\alpha<0.05$. Special tests were classified as either impingement or instability and compiled to report the percentage of athletes in each group that presented with a positive test. For analysis and reporting, any positive impingement or instability test was counted as positive for that athlete creating a new variable, yes or no, and multiple positive tests for a single athlete were still only counted as yes or no. Strength and range of motion characteristics were also be compared with special tests subjective outcomes of pain to determine if an association existed between changes in strength or range of motion and changes in pain or dysfunction using correlation analysis.

Research Question 2

Survey Design.

Using a cross-sectional study design, a survey was disseminated to the 59 teams of the Gulf Swimming Local Swim Committee for distribution to their team members. Through contact with Gulf Swimming, the survey was sent out to all of the currently registered competing teams to provide opportunity for participation from each.

Data collection and procedures.

The target population for this survey was adolescent, year-round, competitive swimmers participating as registered members of USA Swimming within the Gulf Local Swim Committee. The survey participant requirements were that they must be training in the top tier of the team, usually determined by a combination of age and ability, and between the ages of 12-19, which is the age range possible at this training level. This target population represents those athletes who have been participating within the sport and are likely to have encountered the issues addressed in the survey due to their time involved in the sport, their level of achievement, the amount of training they participate in per practice and annually, the type of training they do both in and out of the water.

Survey dissemination was done online, via SoGoSurvey. United States of America Swimming Association, the governing body of competitive club swimming, does not allow direct communication or contact with the members of their affiliated teams without prior consent from the club. Therefore, to recruit the subjects, contact was made through the staff of the teams, either head coaches or senior board members, including a full description of the study and survey, a copy of the survey, and a link to the survey for their review. Staff who chose to allow their team to participate then forwarded the survey link to their team members for dissemination through the survey program. Team registration services, such as Team Unify, have parent member emails registered within their communication systems, thus ensuring that the same information sent to the teams will go to parents of potential participants for review. Those parents who chose to allow their child to participate then allowed their children to complete the survey. SoGoSurvey ensures that the data are deleted upon the request of the survey owner at the close of the study and that no employees have access to surveys while they are being held within the SoGoSurvey database. A click to consent/assent was used prior to being able to complete the survey ensuring the parents and children have understood and agreed to participation prior to starting the survey. Prior to the start of the study the University of Houston IRB approved all documents and procedures.

Instruments and Measures.

To understand the behaviors of swimming with shoulder pain or to participate in an injury prevention program, we adapted previously used surveys, both developed using the Theory of Planned Behavior, to measure items related to four constructs of the model:

Attitude, Subjective Norms, Perceived Behavioral Control, and Intention. The survey items were adapted from two previous surveys that have been used to assess attitudes related to knee (anterior cruciate ligament, ACL) injury among adolescent team sports and coaches. One survey assessed intention to swim with shoulder pain among swimmers, and one survey assessed attitudes and intention to participate in an injury prevention program (Appendix A; Frank, 2014; Gabriel, 2019; Hibberd, 2013; Martinez, 2016). Gabriel, Hoch, and Cramer (2019) reported that final internal consistency reliabilities for the scale used to assess intention to participate in the injury prevention program ranged from 0.60-0.90 for the theory of planned behavior constructs. Reliability and validity of the surveys used in the previous works adapted for the survey of intention to swim with shoulder pain have not been reported. Using the same items from Hibberd and Myers (2013) for attitudes towards swimming with shoulder pain, our survey was expanded to include subjective norms and perceived coaches' beliefs as behavioral control. Items for both surveys were reworded to fit the study population by making them sport and injury specific or reworded to obtain the perceived attitudes and beliefs of the coaches (Table 9). Both surveys had items to solicit the athlete's perspective of the coach's beliefs regarding shoulder pain and injury prevention programs. All survey items used a 5-point Likert scale with responses from "strongly disagree" to "strongly agree". The survey items are included in Appendix B.

Table 9: Examples of rewording to adapt the original survey items.

Original Question	Adapted Question
My participating in an injury prevention program would be beneficial.	My participating in **a shoulder** injury prevention program would be beneficial.
My participating in an injury prevention program would improve my athletic performance.	My participating in **a shoulder** injury prevention program would improve my **swimming** performance.
Shoulder pain is normal and should be tolerated to complete the necessary yards.	**My coach(es) believe that** Shoulder pain is normal and should be tolerated to complete the necessary yards

Data analysis.

Data was compiled and the frequency of responses for each question was tabulated for those reporting no history of SIP or SSI, history of SIP and those with history of SSI.

Due to limited survey response, no further analysis was conducted. Intended data analysis was for data to be complied and the frequency of responses for each question tabulated. Confirmatory factor analysis (CFA) would then have been conducted to evaluate the items' alignment with the intended constructs, as evidence of construct validity. Structural Equation Modeling (SEM) was then planned to determine model fit and test the hypothesized associations among the constructs. Internal consistency reliability of the construct summary scores would be calculated using Cronbach's alpha.

RESULTS

Research Question 1

Subjects.

A total of 42 athletes were initially recruited for this study. Baseline and anthropometric data can be seen in Table 10. In the comparison group, one athlete broke an arm and one athlete developed shoulder pain resulting in cessation from training, so both athletes were dropped from further data collection and analyses. Additionally, four athletes only attended baseline testing and two did not complete testing, so all six were dropped from analysis, leaving a total of 13 in the comparison group. For the intervention group, one athlete broke an arm prior to baseline testing and was excluded from the remainder of the study. Three athletes left the intervention team after baseline testing and one athlete developed a shoulder injury after baseline testing, and all four were excluded from analysis leaving 16 in the intervention group.

Table 10: Anthropometric and swimming exposure data for the comparison group (n=13) and intervention group (n=16). Data are presented as mean (±SD).

	Mean (±SD)		p-value
	Comparison	**Intervention**	
Age	14.38(±1.5)	13.06(±1.06)	p=0.010*
Weight (Kg)	60.44(±7.36)	57.68(±9.18)	p=0.388
Arm Length (cm)	52.44(±3.56)	53.76(±2.94)	p=0.297
Days/week swimming	5.77(±0.6)	5.28(±0.66)	p=0.048*
Hours/day swimming	2.25(±0.65)	1.86(±0.61)	p=0.105
Total Volume (km)	24.27(±9.5)	17.31(±3.01)	p=0.023*

Feasibility and impact.

All athletes that remained in the intervention group were able to complete the exercise program in a 30-minute period, without modification to the program, prior to the in-water training portion of their training. Additionally, when sessions were missed, both by being late or absent, the athletes took home the appropriate exercise band and self reported completion on their own time.

For all athletes there was an increase in difficulty of resistance band used across the 24-week intervention. All athletes started with the yellow resistance band, the lowest level (1.3kg of force). By the end of the 24-week intervention the intervention group achieved the following levels of resistance; one remained at yellow, two increased to green (2.1kg of force), six increased to blue (2.6kg of force), and seven increased to black (3.3kg of force). All advancement in resistance was determined by achieving all 15 repetitions for a particular exercise with proper form on at least two occasions.

Strength and range of motion outcomes.

Reliability testing of the physical therapist conducting the strength testing can be seen in Table 11. Significant testing session by group effects were seen bilaterally for external and internal rotation strength while unilateral differences were found for horizontal abduction strength (Table 12). Testing session by group mean changes can be seen in Figures 3 and 4.

Table 11: Intraclass Correlation Coefficients for strength and Range of Motion outcomes of the physical therapists responsible for testing at baseline, mid-season and post-season.

Outcome	Measure	Intraclass Correlation Coefficient
Strength	**Internal Rotation**	0.90
	External Rotation	0.90
	Horizontal Abduction	0.80
	Shoulder Elevation	0.95
Range of Motion	**Internal Rotation**	0.99*
	External Rotation	0.98*
	Horizontal Adduction	0.99*

* Examiner test-retest reliability previously established (Bailey et al. (2015))

Table 12: Significant differences in strength for testing session by group across the 24-week intervention. Estimate is the group difference in strength between the comparison group and the intervention group.

Variable	Parameter	Estimate	Standard Error	t statistic	p-value
External Rotation Right Arm	Baseline to Mid-season	-0.325	0.098	-3.328	0.003
	Baseline to Post-season	-0.408	0.098	-4.166	<0.001
External Rotation Left Arm	Baseline to Mid-season	-0.241	0.070	-3.460	0.002
	Baseline to Post-season	-0.210	0.113	-1.858	0.075
Internal Rotation Right Arm	Baseline to Mid-season	-0.197	0.077	-2.552	0.018
	Baseline to Post-season	-0.224	0.099	-2.264	0.033
Internal Rotation Left Arm	Baseline to Mid-season	-0.336	0.093	-3.630	0.001
	Baseline to Post-season	-0.324	0.129	-2.516	0.018
Horizontal Abduction Left Arm	Baseline to Mid-season	-0.230	0.070	-3.264	0.003
	Baseline to Post-season	-0.152	0.073	-2.093	0.048
Horizontal Abduction Right Arm	Baseline to Mid-season	-0.129	0.070	-1.829	0.080
	Baseline to Post-season	-0.123	0.066	-1.882	0.073

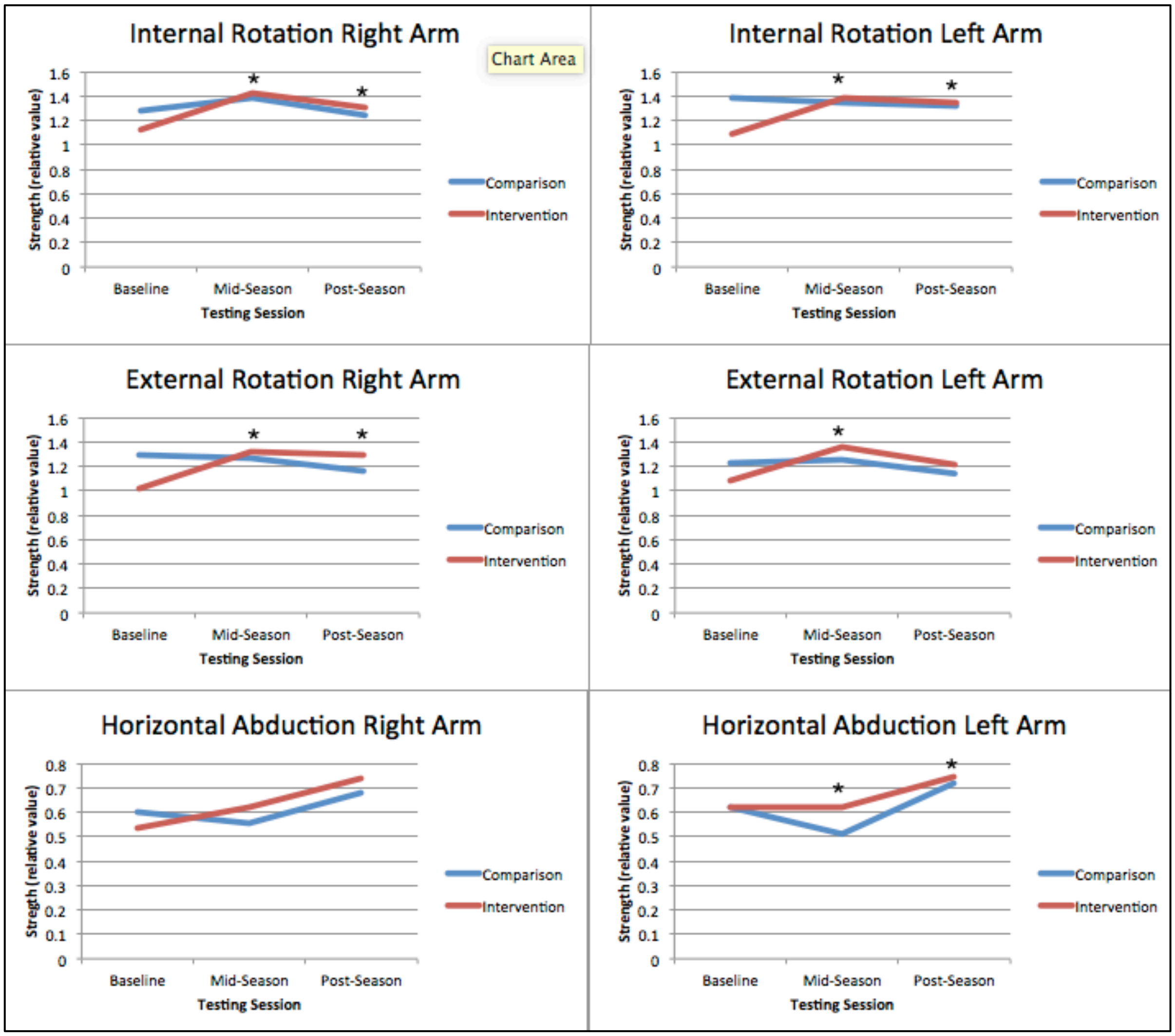


Figure 3: Bilateral strength measurements for internal rotation, external rotation, and horizontal abduction at baseline, mid-season and post-season. * Indicates a significant testing session by group effect from baseline, $p<0.05$.

Range of motion was mostly preserved over the 24-week intervention. Horizontal adduction for the right arm had a significant testing session by group interaction (Figure 5) with the difference between baseline and post-season testing (interaction coefficient = -11.086, t= -4.49, $p<0.001$) no other significant interactions were found (Figures 5 and 6).

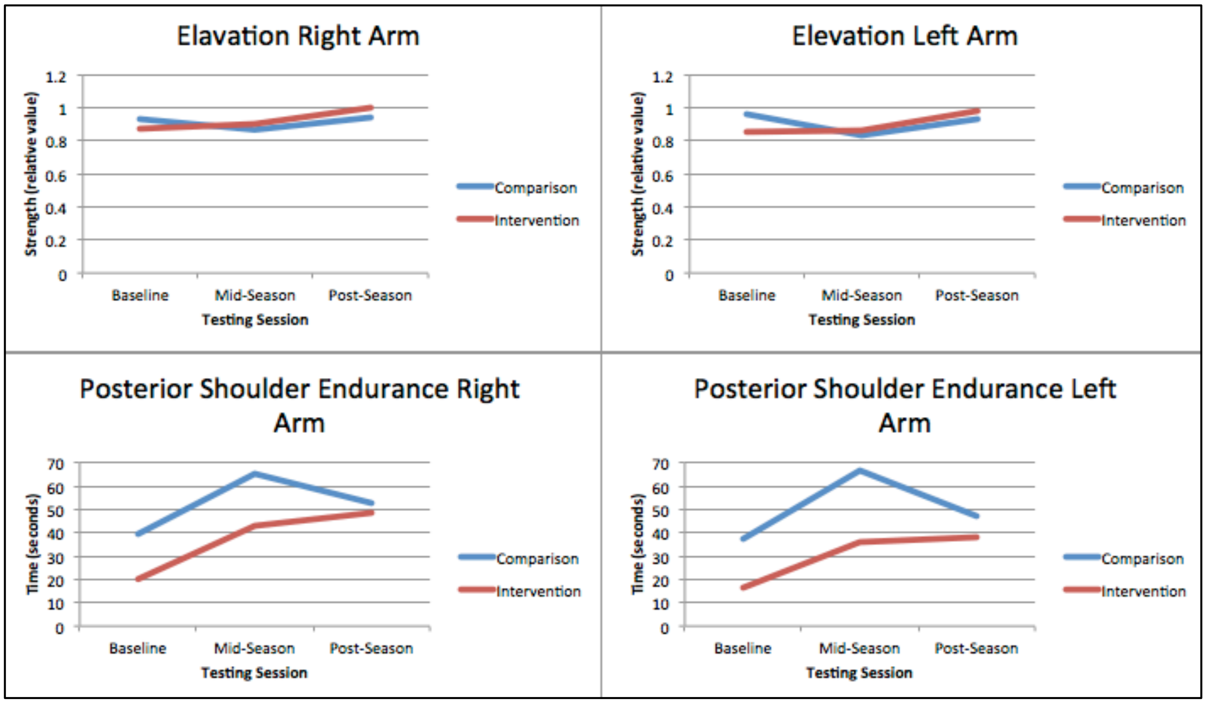


Figure 4: Bilateral strength measurements for elevation and posterior shoulder endurance at baseline, mid-season and post-season.

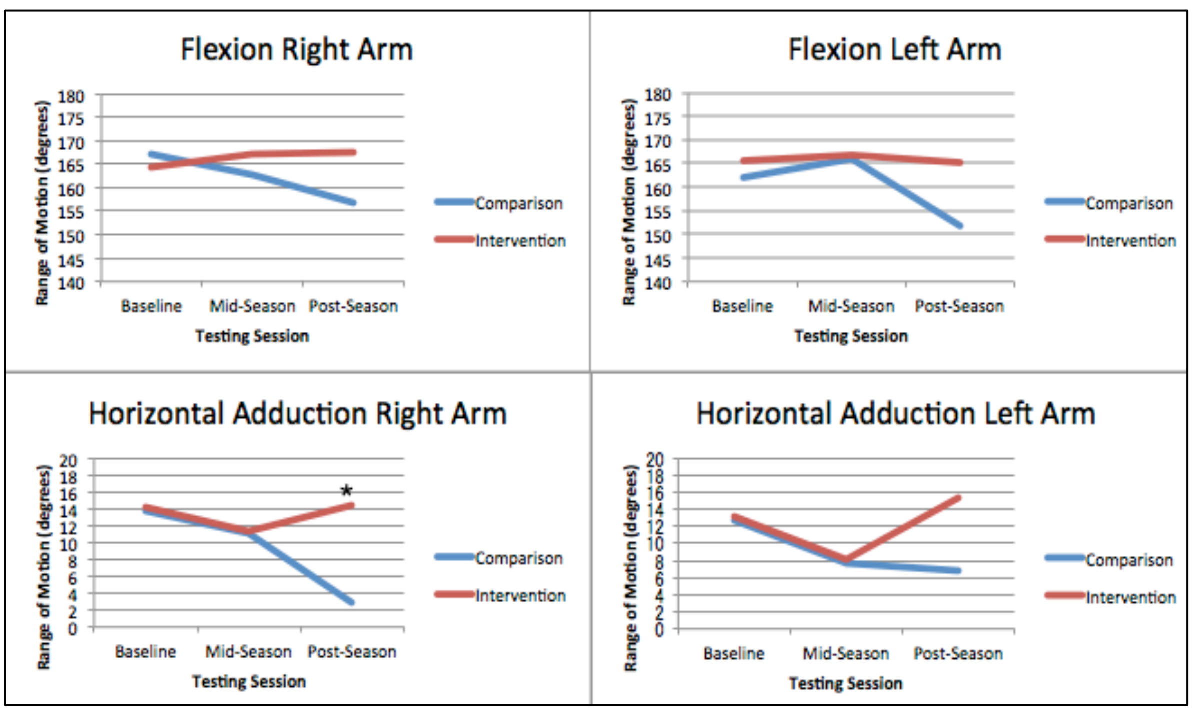


Figure 5: Bilateral range of motion measurements for flexion and horizontal adduction at baseline, mid-season and post-season. * Indicates a significant testing session by group effect from baseline, $p<0.05$.

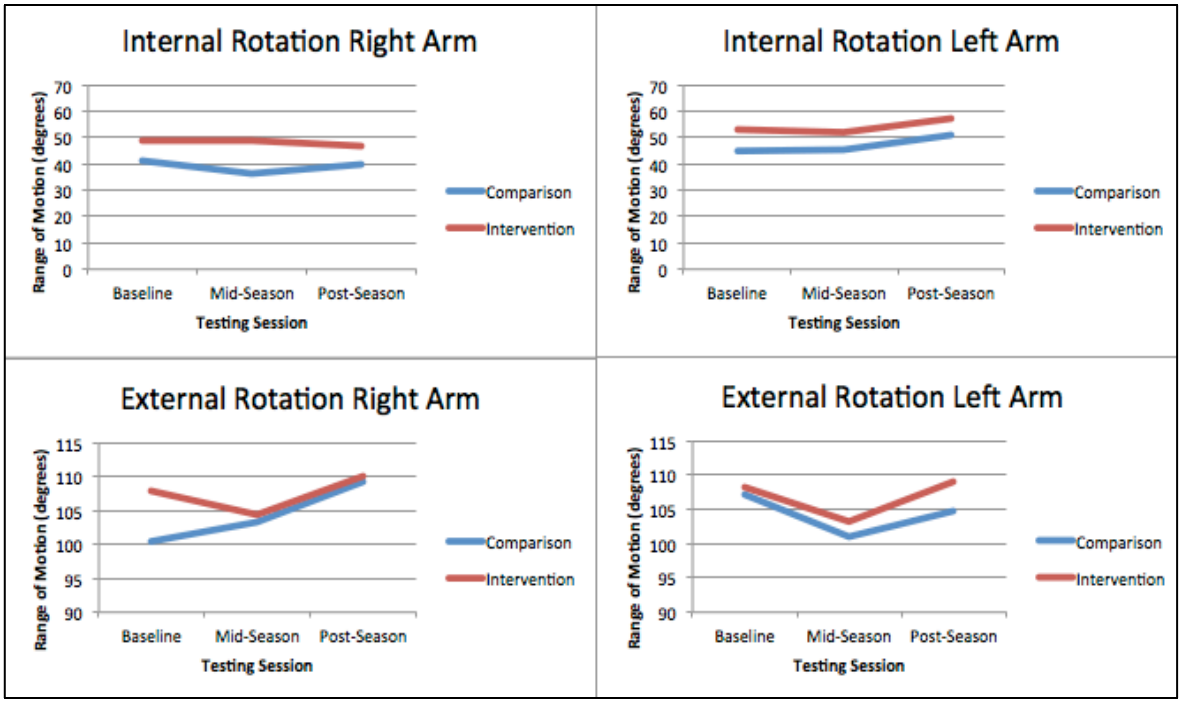


Figure 6: Bilateral range of motion measurements for internal and external rotation at baseline, mid-season and post-season.

Impingement and instability.

The total number of athletes and the percentage of the sample represented who had a positive impingement test at all three testing sessions can be seen in Table 13. The percentage of athletes with bilateral impingement or instability can be seen in Figures 7 and 9, respectively, while the percentage with unilateral impingement and instability can be seen in Figures 8 and 10, respectively. Impingement and instability were not significantly correlated with strength, range of motion or measures of swimming exposure. Impingement was significantly correlated with satisfaction of current shoulder function (satisfaction), the ability to swim with usual technique (technique), history of significant interfering shoulder pain (SIP), history of significant shoulder injury (SSI), and experiencing pain in the week of testing while instability was significantly correlated with shoulder pain while at rest (Table 14). Satisfaction was negatively correlated indicating that with impingement present there was less satisfaction. Technique, SIP, SSI, and pain this week were all positively correlated indicating that impingement resulted in more difficulty swimming with usual technique, positive history of SIP and SSI, and positive pain in the current week of testing respectively. Instability was negatively correlated with pain at rest indicating that those with instability presented with less pain while at rest. Variables significantly correlated with impingement had significant correlations with other variables of interest and can be seen in Table 15.

Table 13: Total number of positive special tests for impingement and instability. Data are presented as total count and the percentage of the sample represented of n=13, 10, 11 for the comparison group and 16, 12, 13 for the intervention group respectively). Data are presented as a percentage of the sample per group.

Total Positive Impingement and Instability Tests		**Comparison Group**		**Intervention Group**	
		Count	**Percentage**	**Count**	**Percentage**
Impingement	**Baseline**	5	38.5	3	18.8
	Mid-Season	5	50.0	4	33.3
	Post-Season	4	36.4	9	69.2
Instability	**Baseline**	5	38.5	7	43.8
	Mid-Season	6	60.0	4	33.3
	Post-Season	3	27.3	8	61.5

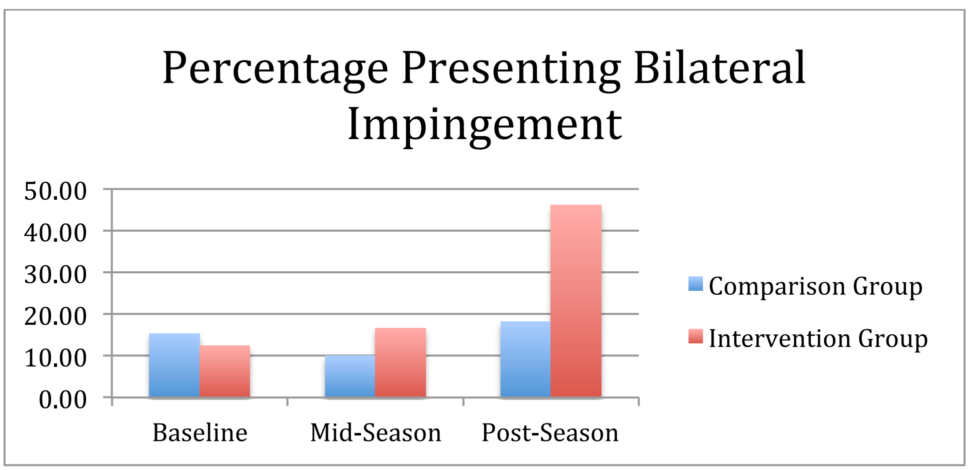


Figure 7: Special test results for positive bilateral impingement at baseline, mid-season, and post-season for both comparison and intervention groups (percentage based on n=13, 10, 11 for the comparison group and 16, 12, 13 for the intervention group respectively). Data are presented as a percentage of the sample per group.

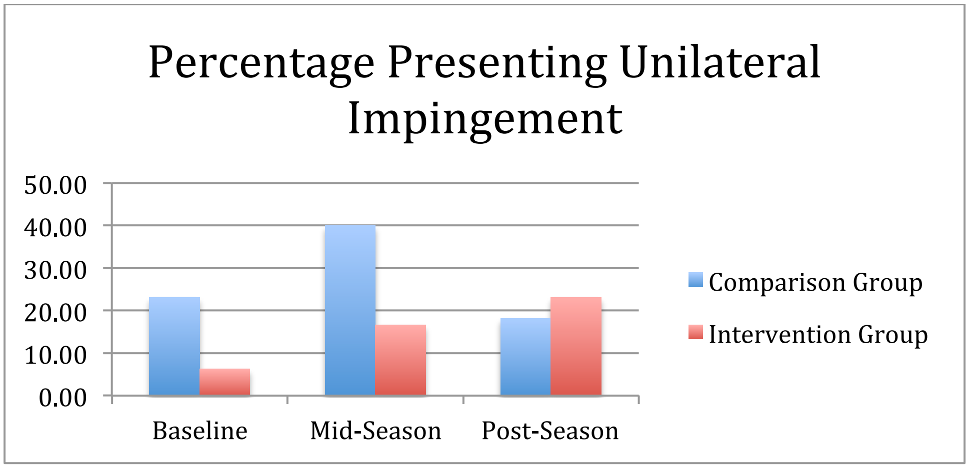


Figure 8: Special test results for positive unilateral impingement at baseline, mid-season, and post-season for both comparison and intervention groups. (percentage based on n=13, 10, 11 for the comparison group and 16, 12, 13 for the intervention group respectively). Data are presented as a percentage of the sample per group.

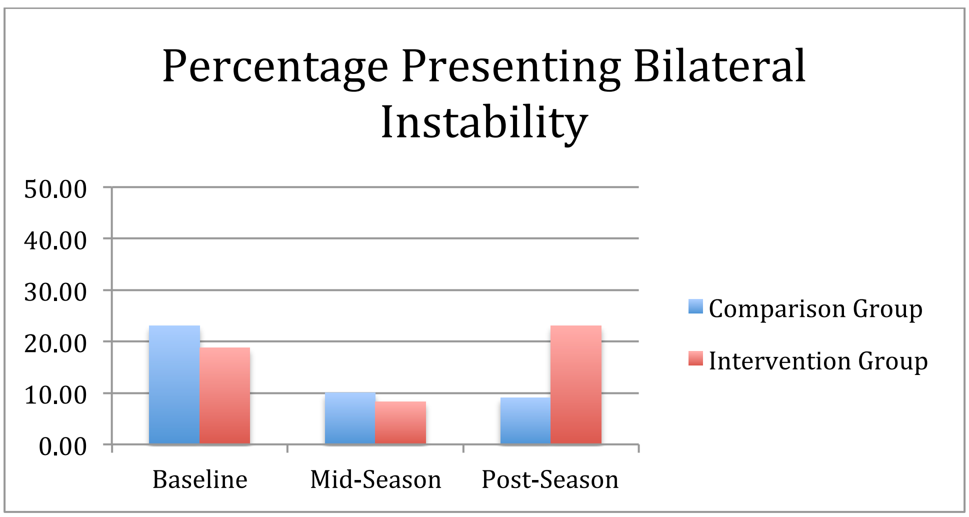


Figure 9: Special test results for positive bilateral instability at baseline, mid-season, and post-season for both comparison and intervention groups. (percentage based on n=13, 10, 11 for the comparison group and 16, 12, 13 for the intervention group respectively). Data are presented as a percentage of the sample per group.

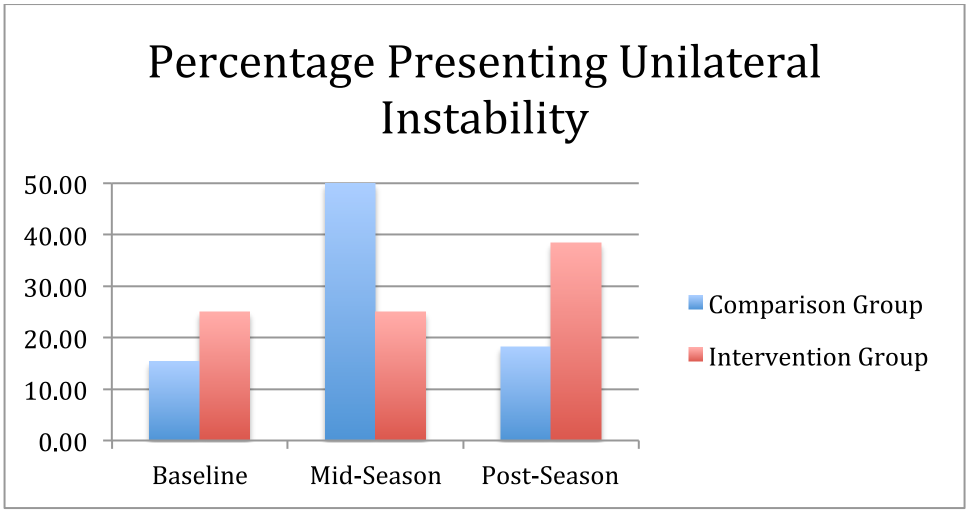


Figure 10: Special test results for positive unilateral instability at baseline, mid-season, and post-season for both comparison and intervention groups. (percentage based on n=13, 10, 11 for the comparison group and 16, 12, 13 for the intervention group respectively). Data are presented as a percentage of the sample per group.

Table 14: Variables significantly correlated with impingement or instability across the 24-week study period.

Special Test Category	Variable	Correlation Coefficient*	p-value
Impingement	Satisfaction of current shoulder function	-0.307	0.007
	Ability to swim with usual technique	0.253	0.030
	History of significant interfering pain	0.311	0.007
	History of significant shoulder injury	0.273	0.018
	Experiencing pain the week of testing	0.335	0.003
Instability	Pain at rest	-0.259	0.026

*Point biserial correlation coefficients.

Table 15: Correlations with the variables correlated with impingement

Variables correlated with Impingement	Variable	Correlation Coefficient*	p-value	Description
Satisfaction of current shoulder function	**Pain at rest**	-0.320	0.004	Increased pain at rest was associated with less satisfaction.
	Pain with normal activities	-0.436	<0.001	Increased pain with normal activity was associated with less satisfaction.
	Pain with strenuous activities	-0.436	<0.001	Increased pain with strenuous activity was associated with less satisfaction.

	Ability to swim with usual technique	-0.248	0.026	Increased difficulty to swim with usual technique was associated with less satisfaction.
	Swimming because of shoulder pain	-0.314	0.004	Increased difficulty to swim due to pain was associated with less satisfaction.
	Swimming as well as you would like	-0.236	0.034	Increased difficulty to swim as well as you would like was associated with less satisfaction.
	History of significant interfering pain	-0.464	<0.001	History of SIP was associated with less satisfaction.
	History of significant shoulder injury	-0.280	0.011	History of SSI was associated with less satisfaction.
	Experiencing pain the week of testing	-0.358	0.001	Experiencing pain the week of testing was associated with less satisfaction.
	Consulting a healthcare worker in the past 6 months	-0.354	0.001	Having to consult a healthcare worker in the last six months was associated with less satisfaction.
	Number of hours a day of swimming	0.324	0.003	The more number of hours swam per day was associated with greater satisfaction.
Ability to swim with usual technique	**Pain with strenuous activities**	0.393	<0.001	Increased pain with strenuous activity was associated with increased difficulty using usual technique.
	Swimming because of shoulder pain	0.348	0.001	Increased difficulty to swim due to pain was associated with increased difficulty using usual technique.
	Swimming as well as you would like	0.352	0.001	Increased difficulty to swim as well as you would like was associated with increased difficulty using usual technique.
	Experiencing pain the week of testing	0.300	0.007	Experiencing pain the week of testing was associated with increased difficulty using usual technique.
	Number of days a week of swimming	0.244	0.029	More days a week swimming was associated with increased difficulty using usual technique.
	Total volume of swimming	0.319	0.004	Larger total volume of swimming was associated with increased difficulty using usual technique.
History of significant interfering pain	**Pain with normal activities**	0.306	0.005	Increased pain during normal activities was associated with history of SIP .
	Pain with strenuous activities	0.352	0.001	Increased pain during strenuous activities was associated with history of SIP .
	History of significant shoulder injury	0.679	<0.001	History of SSI was associated with positive history for SIP.

	Experiencing pain the week of testing	0.276	0.012	Experiencing pain the week of testing was associated with a history of SIP.
	Consulting a healthcare worker in the past 6 months	0.366	0.001	Having to consult a healthcare worker in the last six months was associated with a history of SIP.
	Number of hours a day of swimming	-0.319	0.003	The more number of hours swam per day was associated with no history of SIP.
	Body Weight	0.306	0.004	Increased body weight was associated with a history of SIP.
History of significant shoulder injury	**Consulting a healthcare worker in the past 6 months**	0.557	<0.001	Having to consult a healthcare worker in the last six months was associated with a history of SSI.
Experiencing pain the week of testing	**Pain with normal activities**	0.553	<0.001	Increased pain with normal activity was associated with experiencing pain the week of testing.
	Pain with strenuous activities	0.476	<0.001	Increased pain with strenuous activity was associated with experiencing pain the week of testing.
	Swimming because of shoulder pain	0.629	<0.001	Increased difficulty to swim due to pain was associated with experiencing pain the week of testing.
	Swimming as well as you would like	0.430	<0.001	Increased difficulty to swim as well as you would like was associated with experiencing pain the week of testing.

*Pearson product moment correlation coefficients for continuous variables and point biserial correlation coefficients for dichotomous variables.

Research Question 2

Subjects.

A total of 59 teams were contacted via email for participation in the survey. Initially there was a read rate of 43% of clubs with two emails bouncing back. Within the system five reminder emails were allowed and used in order to try and increase response rate. Final read rate of the emails rose to 52% with two bouncing back and one team blocking email transmission. Of the 52% of teams that read the email three teams participated meaning that the system registered that someone form that team completed the survey. A total of 16 responses were received from those three teams, and 13 completed surveys. Characteristics of the survey participants can be seen in Table 16. Data has been separated between those with no previous history of SIP or SSI (n=4), those with a history of SIP but not SSI (n=5), and those with a history of SSI (n=4), responses can be seen in Appendix A Tables 21-28.

Table 16: Age and swimming characteristics of survey participants who have experienced no pain or injury (n=4), significant interfering shoulder pain (n=5) and significant shoulder injury (n=4).

History of Pain	Age	Practices per Week	Yards per Practice	Total Volume
No Previous History of SIP or SSI	16 (±1.15)	6 (±1)	4,000 (±1,080.12)	21,500 (±5,196.15)
Previous History of Significant Interfering Shoulder Pain (SIP)	16 (±1.67)	7 (±1.14)	5,525 (±411.3)	38,575 (±4,403.313)
Previous History of Significant Shoulder Injury (SSI)	16 (±0.82)	7 (±2.16)	5,500 (±1,500)	42,833 (±25,280.1)

Note: 1 respondent from the SIP group and 1 respondent from the SSI group did not provide enough information to calculate total volume

Survey response scores.

Scores from respondents indicate that as injury history increases in severity, views toward swimming with shoulder pain shift from more agreeable to more disagreeable at all levels of pain (Table 17). No athlete agreed that swimming with a severe level of pain was necessary. Those who had not experienced pain or injury rated their teammates views toward swimming with pain or injury as less favorable than they rated themselves. Those who had experienced pain or injury, however, rated their teammates views as more favorable than they rated their own views (Table 17). Additionally, those without history of pain or injury agreed more with statements that their coach believed swimming with mild or moderate pain was necessary while those who had experienced pain or injury disagreed more with those statements (Table 18). Intention to swim with pain was higher in those with no previous history of pain or injury and those who had mostly disagreed. All athletes regardless of injury history had positive attitudes toward injury prevention programs as well as positive perceived norms (Table 19). Based on the scoring, athletes mostly agreed with statements of behavioral control and intention to participate in an injury prevention program however, the scores lower due to more neutrality to statements (Table 20).

Table 17: Summary Scores for Attitudes and Perceived Subjective Norms towards swimming with pain for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Attitude: No Previous History of SIP or SSI	**Score**	***Perceived Subjective Norm: No Previous History of SIP or SSI***	**Score**
Swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.		**My teammates believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.**	
Mild	5	*Mild*	2
Moderate	3	*Moderate*	-2
Severe	-4	*Severe*	-6
Taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	-3	**My teammates think that taking time off swimming due to shoulder injury is not a practical option to succeed at a high level.**	-3
Attitude: Previous History of SIP but not SSI		***Perceived Subjective Norm: Previous History of SIP but not SSI***	
Swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.		**My teammates believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.**	
Mild	1	*Mild*	2
Moderate	-4	*Moderate*	-2
Severe	-9	*Severe*	-9
Taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	-3	**My teammates think that taking time off swimming due to shoulder injury is not a practical option to succeed at a high level.**	-1
Attitude: Previous History of SSI		***Perceived Subjective Norm: Previous History of SSI***	
Swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.		**My teammates believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.**	
Mild	0	*Mild*	1
Moderate	-5	*Moderate*	-1
Severe	-7	*Severe*	-4
Taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	-1	**My teammates think that taking time off swimming due to shoulder injury is not a practical option to succeed at a high level.**	2

Table 18: Summary Scores for Behavioral Control and Intention towards swimming with pain for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Behavioral Control: No Previous History of SIP or SSI	**Score**	***Intention: No Previous History of SIP or SSI***	**Score**
My coach(es) believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.		**I intend to swim with ____ pain because it will go away when I taper**	
Mild	3	*Mild*	3
Moderate	3	*Moderate*	5
Severe	-3	*Severe*	-6
My coach(es) think taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	0	**I do not intend to swim with any amount of shoulder pain**	-3
Behavioral Control: Previous History of SIP but not SSI		***Intention: Previous History of SIP but not SSI***	
My coach(es) believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.		**I intend to swim with ____ pain because it will go away when I taper**	
Mild	0	*Mild*	2
Moderate	-5	*Moderate*	-5
Severe	-9	*Severe*	-9
My coach(es) think taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	1	**I do not intend to swim with any amount of shoulder pain**	-2
Behavioral Control: Previous History of SSI		***Intention: Previous History of SSI***	
My coach(es) believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.		**I intend to swim with ____ pain because it will go away when I taper**	
Mild	0	*Mild*	0
Moderate	-5	*Moderate*	-3
Severe	-6	*Severe*	-6
My coach(es) think taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	0	**I do not intend to swim with any amount of shoulder pain**	-1

Table 19: Summary Scores for Attitudes and Perceived Subjective Norms towards injury prevention programs for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Attitude: No Previous History of SIP or SSI	**Score**	***Perceived Subjective Norm: No Previous History of SIP or SSI***	**Score**
My participation in a shoulder injury prevention program would______		**My _____ would approve of my participation in a shoulder injury prevention program**	
be beneficial	5	*healthcare provider*	4
decrease my chances of having a shoulder injury	5	*coach/strength coach*	5
improve my performance	3	*parents*	5
improve my knowledge of shoulder injuries and shoulder injury prevention programs	5	*teammates*	4
take too much time	-3		
be dependent on the location of the program	4		
Attitude: Previous History of SIP but not SSI		***Perceived Subjective Norm: Previous History of SIP but not SSI***	
My participation in a shoulder injury prevention program would______		**My _____ would approve of my participation in a shoulder injury prevention program**	
be beneficial	8	*healthcare provider*	6
decrease my chances of having a shoulder injury	6	*coach/strength coach*	7
improve my performance	5	*parents*	8
improve my knowledge of shoulder injuries and shoulder injury prevention programs	9	*teammates*	5
take too much time	-4		
be dependent on the location of the program	6		
Attitude: Previous History of SSI		***Perceived Subjective Norm: Previous History of SSI***	
My participation in a shoulder injury prevention program would______		**My _____ would approve of my participation in a shoulder injury prevention program**	
be beneficial	4	*healthcare provider*	4
decrease my chances of having a shoulder injury	3	*coach/strength coach*	5
improve my performance	2	*parents*	4
improve my knowledge of shoulder injuries and shoulder injury prevention programs	5	*teammates*	4
take too much time	-3		
be dependent on the location of the program	2		

Table 20: Summary Scores for Behavioral Control and Intention towards injury prevention programs for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Behavioral Control: No Previous History of SIP or SSI	**Score**	***Intention: No Previous History of SIP or SSI***	**Score**
I am confident that I can participate in a shoulder injury prevention program	5	I intend to participate in a shoulder injury prevention program.	4
My participation in a shoulder injury prevention program is up to me.	4	If my team was participating in a shoulder injury prevention program, I would participate, too.	5
If my entire team was participating in a shoulder injury prevention program, I would be more likely to participate.	4	If I was given a shoulder injury prevention program to perform at home, I would participate.	4
If there were evidence shoulder injury prevention programs improved athletic performance, I would be more likely to participate.	5	If a health care provider led a shoulder injury prevention program session, I would attend.	2
If I had access to a shoulder injury prevention program, I would participate.	4		
Behavioral Control: Previous History of SIP but not SSI		***Intention: Previous History of SIP but not SSI***	
I am confident that I can participate in a shoulder injury prevention program	4	I intend to participate in a shoulder injury prevention program.	2
My participation in a shoulder injury prevention program is up to me.	4	If my team was participating in a shoulder injury prevention program, I would participate, too.	8
If my entire team was participating in a shoulder injury prevention program, I would be more likely to participate.	9	If I was given a shoulder injury prevention program to perform at home, I would participate.	6
If there were evidence shoulder injury prevention programs improved athletic performance, I would be more likely to participate.	9	If a health care provider led a shoulder injury prevention program session, I would attend.	2
If I had access to a shoulder injury prevention program, I would participate.	5		
Behavioral Control: Previous History of SSI		***Intention: Previous History of SSI***	
I am confident that I can participate in a shoulder injury prevention program	2	I intend to participate in a shoulder injury prevention program.	1
My participation in a shoulder injury prevention program is up to me.	2	If my team was participating in a shoulder injury prevention program, I would participate, too.	6
If my entire team was participating in a shoulder injury prevention program, I would be more likely to participate.	6	If I was given a shoulder injury prevention program to perform at home, I would participate.	5
If there were evidence shoulder injury prevention programs improved athletic performance, I would be more likely to participate.	4	If a health care provider led a shoulder injury prevention program session, I would attend.	3
If I had access to a shoulder injury prevention program, I would participate.	3		

DISCUSSION

The purpose of this study was to determine feasibility and impact of an in-season strength training and stretching program in adolescent, year-round, competitive swimmers. Feasibility was assessed by the ability to implement the program as intended, while impact was determined by assessing changes in strength, range of motion, and signs of impingement or instability across a 24-week training period. The primary finding in this study was that an in-season strength and stretching program, which follows current ACSM (2018) guidelines, is feasible and impactful for adolescent swimmers.

Feasibility

In the present study, the intervention group was afforded a 30-minute period to perform the intervention three days a week, prior to the athletes swimming. This was enough time to perform the intervention program as designed, without modification. Tate et al. (2015), reported that swimmers age 11-12, 13-14, and 15-18 conducted an average of 28.79, 36.13, and 41.45 minutes of dry land training on 3.16, 3.94, and 4.22 days per week respectively. Therefore, the current intervention will feasibly fit within the average limitations for conducting dry land training in the age range of 11-18, as reported by Tate et al. (2015). However, with the wide standard deviations reported, some teams may not be achieving the 30-minutes three days a week necessary to implement this specific intervention. A potential barrier to implementing the training program prior to in water training is the possibility of fatiguing the swimmers. Batalha, Paixao, Jose Silva, Costa, Mullen, and Barbosa (2020) recently addressed this concern. In a group of 23 young male and female swimmers, age 16.43 (±1.38), they found that shoulder rotator strength, endurance and balance are not significantly reduced following a shoulder injury prevention program consisting of shoulder press, external rotation, internal rotation, and shoulder flexion. Based on their findings, coaches could implement a strength training program prior to in-water training without substantial concerns about fatigue, as was done in the present study (Batalha et al., 2020).

Additionally, Tate et al. (2015) reported many different types of dry land training in this age range with only 42.2% of age group swimmers using exercise bands, the primary exercise tool for strength training in the present study. More specifically, similar exercises to the intervention exercises used in the present study were only reportedly being done in about 15-30% and 50-65% of age group swimmers for upper extremity and core strengthening respectively (Tate, 2015). While the program could feasibly be implemented in the time provided, there could be barriers to how much of the current training program coaches would be willing to sacrifice to implement such a program successfully. Barriers such as this raise questions that, to my knowledge, have not yet been investigated but relate directly to the feasibility of implementing an intervention such as the one in the present study. For example, if a team only has 30-minutes three days a week, would they be willing to trade everything they currently do to perform a research-based training program? Or, for teams that conduct longer and more frequent dry land training programs, how much would they be willing to adapt in order to incorporate research-based training? Future research should be conducted to determine how coaches could implement a research-based intervention as a part of their normal training regimen.

Impact

In order to assess impact this study looked at changes in strength, range of motion and tests of impingement or instability across a 24-week intervention period. Primary findings indicate that the intervention did increase strength and preserve range of motion; however, results of impingement or instability were less clear.

Strength.

At the most basic level of impact on improved strength is assessing the change in strength over time. One way to assess change in strength over time is examining the progression of resistance used. Primary outcome measures were peak isometric contractions using a handheld dynamometer. However, increased resistance used for a given exercise likely indicates improvement in strength as well due to the ability to move a higher load for a given number of repetitions. In the present study, the majority of the intervention group progressed to the black resistance band level, which represents an increase in resistance of about 250%, and all but one athlete progressed beyond the starting level. In addition to simply increasing the amount of resistance used to complete the exercises, a measure of change in strength by some form of objective assessment is a more robust measure of impact for an intervention.

By comparing change in maximal voluntary contraction between groups across a 24-week intervention, the present study built upon the previous research studying strength training interventions in competitive swimmers. Previous research has shown that in-season interventions do have some impact on strength. Manske et al. (2015) revealed larger percentage increases in strength over a 12-week training period, but the only significant difference between the intervention and comparison group was found for external rotation. Hibberd et al. (2010) found trends towards increased strength over six weeks but no statistically significant differences between intervention and comparison groups were found. Van de Velde et al. (2011) assessed a strength, lower repetition, versus endurance, higher repetition, training program over 12 weeks. Both groups completed the same exercises, with the only difference being the strength or endurance repetition scheme, and obtained significant increases in strength, but there was no difference in peak force or muscle endurance between the two groups. These studies show that in-season interventions do have the potential to impact strength; however, the duration of the intervention and the frequency of training might need to be adjusted to produce meaningful differences between an intervention group and comparison group. To ensure the exposure to the intervention was sufficient, the present study followed current guidelines for resistance training in youth (ACSM, (2018)) and increased the intervention period to 24-weeks.

Internal and external rotation.

Results of this study show that the intervention increased internal and external rotation strength bilaterally across the 24-week training period. It is important to note that internal rotation was not directly trained as a part of the intervention. However, instructions were to control the band for each exercise, so it is possible that the athletes were getting some training effect on internal rotation by way of the synergistic role that the internal rotators play in acting as a stabilizer with various other exercises that were a part of the intervention. In contrast, the comparison group had a progressive downward trend for both of these measures. The muscles activated in both of these movements are active in freestyle, the primary stroke used in training, with the internal rotators being the more active muscle group. It is possible that the cumulative fatigue across the 24-weeks is detrimental to peak force production for these movements, although this was not within the scope of the present study and warrants further investigation.

The intervention group had a greater increase in strength over the first 12 weeks and a slight decrease over the second 12 weeks of the intervention. This could be due to the way that training is progressed over the course of the season. Calculations for volume (total kilometers) in the present study were done by the using the data provided by the coach for average attendance multiplied by average kilometers. A limitation of this is that it does not account for swim exposure across the season, week by week for example. Training parameters typically would have increased in some systematic way over the course of the season, and the timing of testing sessions was built around this such that we would be testing at the end of a training cycle, while the athletes were tapered, around a championship meet. In an investigation of periodization 25-weeks prior to competition, Hellard, Avalos-Fernandes, Lefort, Pla, Mujika, Toussaint and Pyne (2019) showed that peak performance was associated with progressive increase in training load.

Hellard et al., (2019) showed that a 25-week period has two typical macrocycles of 12-16 weeks, which closely mirrors the seasonality of the current study group, with two load peaks followed by load decreases for competition. The first training cycle, over the first 12-weeks, represents the period of training when the athlete is building their training base, and therefore the training volume would have started lower and increased steadily in the first 12-weeks. Recommendations for endurance athletes are to begin by increasing a cardiovascular base, which involves slowly and systematically progressing the frequency, duration and intensity of training (Baechle and Earle, 2008). In swimming, this would happen over the first training cycle from August to December.

The second training cycle builds upon the first, meaning that the training volume does not need to increase as much due to the training base already being established, and focuses more on increases of intensity. The intervention group may have been able to increase strength more effectively in the base building phase, but during the second training cycle with its increased intensity they fell into similar trends of decreasing peak force production, as seen in the comparison group. Future studies should consider periodization of the in-water training cycle to better understand how this may impact the effectiveness of strength training interventions.

An additional explanation for the apparent plateau effect in the intervention group could be in the timing of post-season testing. While every attempt was made to test during the period when training load was lowest, scheduling and logistical limitations did not allow us to assess both teams in this period. Our post-season testing for the comparison group was done when scheduled, but the intervention group testing was pushed back and changed from a Saturday morning, as all previous data collections were done, to a Tuesday evening. This change could have potentially impacted the ability for the intervention group to perform at their best due having gone through a typical school day and other sport commitments for some.

Horizontal abduction.

Horizontal abduction strength changed similarly bilaterally, although this change in strength was only significantly different in the left arm. Athletes in the comparison group showed a slight decline in strength mid-season with a subsequent increase post-season. There was no known change in the comparison groups training that would have directly impacted the trajectory of strength for this variable. As previously mentioned, the comparison group was tested while rested, as originally planned for post-season testing. It is possible that the impact of fatigue is lower at this point having reduced the volume of training when following a typical training schedule involving a taper period. While many of the same muscles are activated in horizontal abduction as internal/external rotation (Hibberd et al., 2010), the larger trapezius muscle, active in horizontal abduction, may have recovered more due to its lack of activity in freestyle, the primary swimming stroke. Results of the intervention group could support this as well. While the internal and external rotation improvements were slightly decreased at post-season testing, horizontal abduction strength continued to increase. Resumption of training, which might have impacted internal and external rotation strength due to the large amount of use of those muscles in training, might not have the same impact on the larger, less used trapezius muscle.

Elevation.

Shoulder elevation did not significantly change in either group over the 24-week intervention period. This was not unexpected as there was no intervention exercise directly targeting strength improvements for this outcome; however, the deltoids and muscles of the rotator cuff are activated during freestyle swimming (Heinlein & Cosgarea, 2010). This variable represents what changes might be expected due to regular swim training alone or natural improvements in strength due to maturation, for example. The small change in this variable in both the comparison group and the intervention group suggests that with no specificity of training there is little change in strength over the 24-week study period.

Posterior shoulder endurance.

There was no significant group by training session difference for posterior shoulder endurance across the 24-week study. Both groups showed an increase at mid-season testing however, the comparison group declined from mid-season to post-season while the intervention group had a continued, while more modest, improvement in strength. While these differences were not statistically significant, there could be some practical significance to it. Resistance to fatigue is important to maintain normal movement patterns and reduce the chance of overuse injury. Maintaining scapular control maintains the integrity of the shoulder girdle allowing the transfer of power from the body to the arm and, if impaired, the result could be loss of control and increased risk of injury (Burn et al., 2016). Furthermore, it has been reported that even in pain free swimmers can display scapular dyskinesis and scapular stabilizer fatigue in a single training session (Bak, 2010). With the progressive increase in posterior shoulder endurance in contrast to the comparison groups decline seen over the second half of the invention period, the increased resistance to fatigue could have a protective effect.

Range of motion.

It was hypothesized that the intervention would preserve range of motion across the 24-week intervention. Tightness of numerous muscles has been identified in shoulder pathology (Dutton, 2012). The only variable with a significant group by training session difference in the present study was horizontal adduction in the right arm. Both groups had the same declining trend from baseline to mid-season, which continued for the comparison group while the intervention group improved over the second half of the intervention. This could be due to the increased proficiency of the sleeper stretch used in the intervention group across the 24-week period. In the present study the intervention group maintained relatively stable range of motion for flexion and internal rotation while the comparison group displayed similar changes for internal rotation but a decline in flexion. While not statistically significant, this increased stiffness of the latissimus dorsi seen in the comparison group could have some practical significance. This can contribute to the forward shoulder posture commonly seen in overhead athletes which, stretching of tight muscles combined with strengthening of weak muscles, can be improved (Kluemper et al. (2006), Hibberd et al. (2016)). External rotation changed similarly for both groups however, both groups remained over 100 degrees, which was recently included as a part of the overall picture that represents differences between swimmers with pain and those without (Struyf et al., 2017).

Impingement and instability.

Neither impingement nor instability were found to have any discernable pattern in either group, nor were they found to significantly correlate with any measure of strength or range of motion. In the intervention group, both impingement and instability were shown to increase for the final testing session. It is unclear if this observation was confounded by the timing of the final testing session. Previous testing sessions were completed during the rested period, on a Saturday, and in the morning prior to the swim practice. Due to logistical and scheduling challenges, the final session for the intervention group was completed after resuming swim training, on a weekday, in the evening after school. Some participants had also been involved in other sport activities prior to testing. This could, in part, explain the large increase for impingement and instability seen post season compared to the stable or improved results seen mid-season.

Of particular importance could be the resumption of training for the intervention group. One of the extrinsic risk factors for swimmer's shoulder is a sudden or absolute training volume increase (Bak, 2010). In addition, impingement was significantly correlated with experiencing pain the week of testing and the ability to swim with usual technique. Both of these variables have been shown to be related to shoulder pain and injury (Bak, 2010; Chorley et al., 2017). It is probable that the resumption of training exposed the athletes to a sudden volume increase; however, the present study did not collect weekly training volume exposure and therefore this should be considered in future studies.

Previous pain or injury was also significantly correlated with impingement for the participants in this study. As a risk factor for shoulder injury, previous pain and injury has been shown to have an association with shoulder injury (Walker et al, 2012; Tate et al, 2012) at a level of moderate certainty in a review of the literature (Hill et al., 2015). Results of the present study add to the possibility that once injured, more care must be taken to prevent the athlete from being reinjured. This would also suggest that more must be done to reduce the first occurrence of injury, removing a moderate risk factor in the first place.

Of the variables that were significantly correlated with impingement, some could have detrimental effects on the athletes training and progression. For example, decreased ability to swim with usual technique was correlated with positive impingement but that variable was also associated with decreased satisfaction, increased pain, increased difficulty to swim or swim as well as the athlete would like, and was related to a larger total swim exposure in days or volume. While none of those variables were directly correlated with impingement, these variables could indicate that an athlete is on a path towards impingement. It has been established that technique errors while swimming contribute to shoulder impingement (Chorley eat al., 2017; Yanai & Hay, 1998). Even in the absence of current diagnosis of impingement, there may be signs indicating to coaches that impingement may be present or that the athlete is at high risk for impingement. For example, if an athlete has a high swim exposure, difficulty swimming the amount they would like or as well as they would like, and to the point that they are unable to swim with usual technique coaches could look at this as a warning sign that the athlete is at risk for impingement. This could be even more important for those who have experienced pain or injury in the past given the association between those variables and impingement.

Survey of shoulder pain and shoulder injury intervention programs.

While a limited number of respondents could be reached for the present survey, there appears to be useful information that could warrant further investigation. When looking at the data available, some observations between those with a previous history of significant shoulder injury, interfering shoulder pain, and those without could be made. Significant interfering shoulder pain (SIP) was defined as pain that caused cessation or modification of training, competition, or progression of training (Walker et al., 2012). However, this interfering pain did not last for two or more weeks, which would have then been classified as a significant shoulder injury (SSI).

Total volume has been suggested as a predictor of shoulder injury (Hill et al., 2015). In the present survey the average total volume of those with no history of either SIP or SSI was 21,500, those with SIP but not SSI was 38,575, and those with SSI was 42,833. While the sample is small, it does appear that the total exposure to swimming could be related to the incidence of pain and or injury. These variables should be included in future studies with larger samples in order to determine if a relationship truly exists.

It is possible that previous history could drive one's attitudes towards injury or injury prevention as well. When examining the responses toward swimming with pain, those with no history of pain or injury had an attitude of agreement with needing to swim with mild or moderate pain. In contrast, those with history of pain or injury were split on mild pain but mostly disagreed that swimming with moderate pain was necessary. This was similar in the questions related to intention to swim with shoulder pain. It could be that their individual experience has changed their opinion towards swimming with pain, which could be investigated further as a part of a larger study. Identifying potential trends between the groups is less clear for perceived norms or behavioral control in the present study but a larger sample is warranted in order to determine if differences do exist based on an individual's injury history.

When examining the responses for questions about injury prevention programs it appears that most swimmers, regardless of injury history, have positive views. One potential barrier to successful injury prevention programs would be if the athlete perceived the program to have enough value to actually carry out the program. Responses from the present study are encouraging for the possibility of implementing injury prevention programs in this population, but a larger sample would be needed to confirm these views. Another barrier to implementing an injury prevention program would be the coaching staff, thus the views of coaches would need to be determined as well. Future surveys should attempt to determine the socio-cultural factors that could contribute to the high prevalence rates currently reported in the literature. Some important factors that need investigation are the attitudes and beliefs of coaching staff towards shoulder pain in the athlete and injury prevention programs.

Limitations

This study was not without its limitations. In the study design of the strength training intervention, there would have ideally been a true control group and intervention group. This would involve one team, following one training program in the pool while separating the team evenly and randomly into two groups, one for intervention and one for control. This would remove potential confounders such as differences in swim exposure, training methodology, and coaching. This would not be very practical, though. Finding a large enough team to support this design would be difficult and the logistics of two different dry land training routines are impractical. These groups would not be receiving the same training despite being on the same team. Another option would be to randomize at the team level, perhaps first matching teams on various training characteristics, but this would require a very large number of teams and sample size. This makes it very difficult, in any design, to control for training differences between groups.

Another limitation of the present study is the scheduling of follow up testing. In this age group there are many other factors that determine whether or not the athlete attends training, and in this case testing on the day of training. We attempted to mitigate this by making testing sessions known to the teams and participants in advance. Despite these efforts we still experienced decreased numbers at mid-season and post-season testing. Coordinating the testing between practice and competitions was also a limitation. We were able to navigate this successfully for the mid-season testing session but could not work out a solution for the post-season testing. Timing of testing could have been a substantial confounder in some of our results.

The survey was very limited in that the timing of survey release was during the global COVID-19 pandemic, which was outside of our control. Original plans for the survey included initial contact via email with follow ups, in person, as needed. This would likely have increased the response rates to the survey. With only email to rely on, the response rate was low and the final sample very small.

Conclusions

Results of the present study indicate that an in-season strength and stretching program, which follows current recommendations for strength training in youth, with systematic increases in resistance, is feasible and impactful. This program, using minimal and affordable equipment, successfully increased strength in-season over a 24-week period. Implementing the program was possible in a 30-minute period, prior to swimming in this case, which is within the time many teams already participate in dry land training. Despite the use of similar movements in the comparison group, it is recommended that in order to increase strength it is necessary to follow current guidelines when implementing an injury prevention program. Future studies should determine the long-term impact of programs such as the one presented in this study on shoulder pain and injury. Based on the survey data available, it appears that previous history of pain and injury could change the way an athlete views swimming with pain. Additionally, it appears that the swimmers themselves would be receptive to implementing a shoulder injury prevention program, removing a potential barrier to success. A larger study would be necessary to determine if these trends are true of the larger swimming community. Together these results indicate that educating those athletes who have not yet experienced pain or injury that it is not normal or necessary, while implementing an evidence based injury prevention program following current recommendations, could positively impact risk factors within the model and reduce the high prevalence rates for shoulder pain and injury.

APPENDIX A: Frequency of responses to survey questions

Table 21: Attitudes towards swimming with pain for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Attitude	**No Previous History of SIP or SSI**				
Swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild				3	1
Moderate			1	3	
Severe		4			
Taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	1	2		1	
Attitude	**Previous History of SIP but not SSI**				
Swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild		2	1	1	1
Moderate	1	3		1	
Severe	4	1			
Taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	2	1		2	
Attitude	**Previous History of SSI**				
Swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild		2	1	2	
Moderate	1	3			
Severe	3	1			
Taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	2			1	1

Table 22: Perceived subjective norms about swimming with pain for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Perceived Subjective Norm	**No Previous History of SIP or SSI**				
My teammates believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild			2	2	
Moderate		2	2		
Severe	2	2			
My teammates think that taking time off swimming due to shoulder injury is not a practical option to succeed at a high level.		3	1		
Perceived Subjective Norm	**Previous History of SIP but not SSI**				
My teammates believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild		1	1	3	
Moderate	1	2		2	
Severe	4	1			
My teammates think that taking time off swimming due to shoulder injury is not a practical option to succeed at a high level.	1	1	1	2	
Perceived Subjective Norm	**Previous History of SSI**				
My teammates believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild		2		1	1
Moderate		2	1	1	
Severe	2	1		1	
My teammates think that taking time off swimming due to shoulder injury is not a practical option to succeed at a high level.	1	2		2	

Table 23: Behavioral control of swimming with pain for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Behavioral Control	**No Previous History of SIP or SSI**				
My coach(es) believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild			1	3	
Moderate			1	3	
Severe		3	1		
My coach(es) think taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.		1	2	1	
Behavioral Control	**Previous History of SIP but not SSI**				
My coach(es) believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild	1	1		3	
Moderate	2	2		1	
Severe	4	1			
My coach(es) think taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	1	1		2	1
Behavioral Control	**Previous History of SSI**				
My coach(es) believe that swimming with _____ shoulder pain is normal and should be tolerated to complete necessary yardage.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild	1		1	2	
Moderate	1	3			
Severe	2	2			
My coach(es) think taking time off of swimming due to shoulder injury is not a practical option if I want to succeed at a high level.	1		1	2	

Table 24: Intention to swim with pain for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Intention	**No Previous History of SIP or SSI**				
I intend to swim with ____ pain because it will go away when I taper	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild			1	3	
Moderate				3	1
Severe	2	2			
I do not intend to swim with any amount of shoulder pain		3	1		
Intention	**Previous History of SIP but not SSI**				
I intend to swim with ____ pain because it will go away when I taper	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild		1	1	3	
Moderate	2	2		1	
Severe	4	1			
I do not intend to swim with any amount of shoulder pain	2	1		1	1
Intention	**Previous History of SSI**				
I intend to swim with ____ pain because it will go away when I taper	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Mild		2	1		1
Moderate	1	2		1	
Severe	2	2			
I do not intend to swim with any amount of shoulder pain	1	1		2	

Table 25: Attitudes towards shoulder injury prevention programs for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Attitudes	**No Previous History of SIP or SSI**				
My participation in a shoulder injury prevention program would______	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
be beneficial				3	1
decrease my chances of having a shoulder injury				3	1
improve my performance			1	3	
improve my knowledge of shoulder injuries and shoulder injury prevention programs				3	1
take too much time		3	1		
be dependent on the location of the program				4	
Attitudes	**Previous History of SIP but not SSI**				
My participation in a shoulder injury prevention program would______	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
be beneficial				2	3
decrease my chances of having a shoulder injury				4	1
improve my performance		1		3	1
improve my knowledge of shoulder injuries and shoulder injury prevention programs				1	4
take too much time	1	2	2		
be dependent on the location of the program				4	1
Attitudes	**Previous History of SSI**				
My participation in a shoulder injury prevention program would______	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
be beneficial			1	2	1
decrease my chances of having a shoulder injury			2	1	1
improve my performance			2	2	
improve my knowledge of shoulder injuries and shoulder injury prevention programs			1	1	2
take too much time	1	1	2		
be dependent on the location of the program			2	2	

Table 26: Perceived subjective norms of shoulder injury prevention programs for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Perceived Subjective Norm	**No Previous History of SIP or SSI**				
My _____ would approve of my participation in a shoulder injury prevention program	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
healthcare provider			1	2	1
coach/strength coach				3	1
parents				3	1
teammates			1	2	1
Perceived Subjective Norm	**Previous History of SIP but not SSI**				
My _____ would approve of my participation in a shoulder injury prevention program	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
healthcare provider			1	2	2
coach/strength coach		1		1	3
parents				2	3
teammates		1		3	1
Perceived Subjective Norm	**Previous History of SSI**				
My _____ would approve of my participation in a shoulder injury prevention program	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
healthcare provider				4	
coach/strength coach			1	1	2
parents			1	2	1
teammates			1	2	1

Table 27: Perceived behavioral control of participating in shoulder injury prevention programs for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Perceived Behavioral Control	**Previous History of SSI**				
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I am confident that I can participate in a shoulder injury prevention program				3	1
My participation in a shoulder injury prevention program is up to me.				4	
If my entire team was participating in a shoulder injury prevention program, I would be more likely to participate.			1	2	1
If there were evidence shoulder injury prevention programs improved athletic performance, I would be more likely to participate.				3	1
If I had access to a shoulder injury prevention program, I				4	

would participate.					
Perceived Behavioral Control	**Previous History of SIP but not SSI**				
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I am confident that I can participate in a shoulder injury prevention program			2	2	1
My participation in a shoulder injury prevention program is up to me.		1		3	1
If my entire team was participating in a shoulder injury prevention program, I would be more likely to participate.				1	4
If there were evidence shoulder injury prevention programs improved athletic performance, I would be more likely to participate.				1	4
If I had access to a shoulder injury prevention program, I would participate.				5	
Perceived Behavioral Control	**Previous History of SSI**				
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I am confident that I can participate in a shoulder injury prevention program			2	2	
My participation in a shoulder injury prevention program is up to me.			2	2	
If my entire team was participating in a shoulder injury prevention program, I would be more likely to participate.			1		3
If there were evidence shoulder injury prevention programs improved athletic performance, I would be more likely to participate.			1	2	1
If I had access to a shoulder injury prevention program, I would participate.			1	3	

Table 28: Intention to participate in shoulder injury prevention programs for all respondents separated by no history of pain or injury (n=4), history of significant interfering shoulder pain (SIP, n=5), and significant shoulder injury (SSI, n=4).

Intention	**Previous History of SSI**				
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I intend to participate in a shoulder injury prevention program.			1	2	1
If my team was participating in a shoulder injury prevention program, I would participate, too.				3	1
If I was given a shoulder injury prevention program to perform at home, I would participate.			1	2	1
If a health care provider led a shoulder injury prevention program session, I would attend.			2	2	
Intention	**Previous History of SIP but not SSI**				
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I intend to participate in a shoulder injury prevention program.			3	2	
If my team was participating in a shoulder injury prevention program, I would participate, too.				2	3
If I was given a shoulder injury prevention program to perform at home, I would participate.			1	2	2
If a health care provider led a shoulder injury prevention program session, I would attend.		1	1	3	
Intention	**Previous History of SSI**				
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I intend to participate in a shoulder injury prevention program.			3	1	
If my team was participating in a shoulder injury prevention program, I would participate, too.			1		3
If I was given a shoulder injury prevention program to perform at home, I would participate.			1	1	2
If a health care provider led a shoulder injury prevention program session, I would attend.			1	3	

APPENDIX B: Example of the survey
Identification Questions
Age
Gender
Swimming Background (open ended)
Do you participate in another organized sport?
If no, at what age did you begin ONLY swimming for sport participation?
On average, how many yards per practice do you swim?
In a typical week, how many days per week do you swim?

Have you ever experienced shoulder pain that requires you to either stop training/competition or modify training? YES NO
Have you ever experienced a shoulder pain that required you to either stop training/competition or modify training for two or more weeks? YES NO

For the following section, please indicate if you strongly agree, agree, neutral, disagree or strongly disagree.
Intention of swimming with shoulder pain
Attitude
- My swimming with mild shoulder pain is normal and should be tolerated in order to complete the necessary yardage in practice.
- My swimming with moderate shoulder pain is normal and should be tolerated in order to complete the necessary yardage in practice.
- My swimming with severe shoulder pain is normal and should be tolerated in order to complete the necessary yardage in practice.
- Taking time off swimming due to shoulder injury is not a practical option if I want to succeed at a high level.

Perceived Subjective Norm
- My teammates believe swimming with mild shoulder pain is normal and should be tolerated in order to complete the necessary yardage in practice.
- My teammates believe swimming with moderate shoulder pain is normal and should be tolerated in order to complete the necessary yardage in practice.
- My teammates believe swimming with severe shoulder pain is normal and should be tolerated in order to complete the necessary yardage in practice.
- My teammates think that taking time off swimming due to shoulder injury is not a practical option to succeed at a high level.

Behavioral Control
- My coach(es) believes that mild shoulder pain is normal and should be tolerated to complete the necessary yards.
- My coach(es) believes that moderate shoulder pain is normal and should be tolerated to complete the necessary yards.
- My coach(es) believes that severe shoulder pain is normal and should be tolerated to complete the necessary yards.
- My coach(es) think that taking time off swimming due to shoulder injury is not a practical option to succeed at a high level.

Behavioral Intention

- I intend to swim with mild pain because it will go away when I taper.
- I intend to swim with moderate pain because it will go away when I taper.
- I intend to swim with severe pain because it will go away when I taper.

Intention of participation in a shoulder Injury Prevention Program

Attitudes

- My participating in a shoulder injury prevention program would be beneficial.
- My participating in a shoulder injury prevention program would be pleasant.
- My participating in a shoulder injury prevention program would decrease my chances of having a shoulder injury.
- My participating in a shoulder injury prevention program would improve my swimming performance.
- My participating in a shoulder injury prevention program would improve my knowledge of shoulder injuries and shoulder injury prevention programs.
- My participating in a shoulder injury prevention program would take too much time.
- My participating in a shoulder injury prevention program would be dependent on the location of the program.

Perceived Subjective Norms

- Most people who are important to me approve of me participating in a shoulder injury prevention program.
- My health care providers (doctor/athletic trainer/physical therapist) would approve of my participation in a shoulder injury prevention program.
- My coach/strength coach would approve of my participation in a shoulder injury prevention program.
- My parents would approve of my participation in a shoulder injury prevention program.
- My teammates/friends would approve of my participation in a shoulder injury prevention program.

Perceived Behavioral Control

- I am confident that I can participate in a shoulder injury prevention program.
- My participation in a shoulder injury prevention program is up to me.
- If my entire team was participating in a shoulder injury prevention program, I would be more likely to participate.
- If there were evidence shoulder injury prevention programs improved athletic performance, I would be more likely to participate.
- If I had access to a shoulder injury prevention program, I would be more likely to participate.

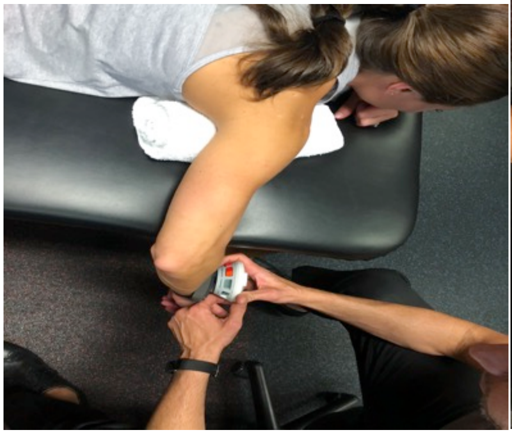
Intention

- I intend to participate in a shoulder injury prevention program.
- If my team was participating in a shoulder injury prevention program, I would participate, too.
- If I was given a shoulder injury prevention program to perform at home, I would participate.
- If a health care provider led a shoulder injury prevention program session, I would attend.

APPENDIX C

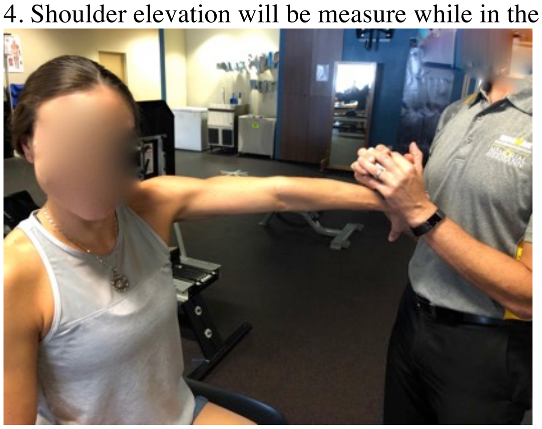
Muscle testing was performed to obtain Maximum Voluntary Isometric Contraction (MVIC) via make test format. The participants other hand is not permitted to stabilize them. The participant's legs were not permitted to stabilize them.

1/2. Isometric muscle strength of IR and ER will be conducted with the patient in prone lying with shoulder abducted to 90 degrees.




3. Shoulder horizontal abduction will be done lying prone with the elbow extended.

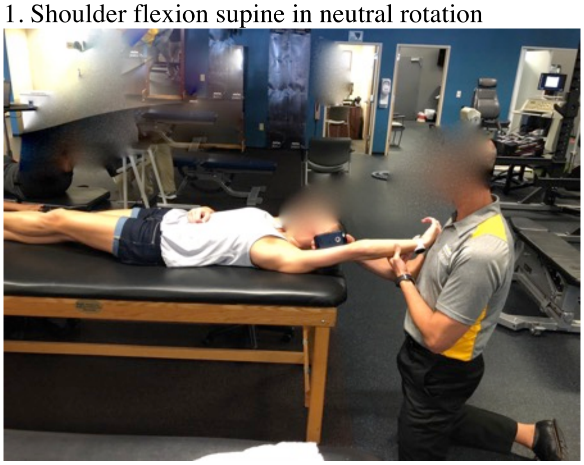
4. Shoulder elevation will be measure while in the full can position (Note this will be done thumb up).



5. Additionally the posterior shoulder endurance test will be performed.

Passive Range of motion testing of both shoulders will be performed with inclinometers according to standard procedure for:

1. Shoulder flexion supine in neutral rotation

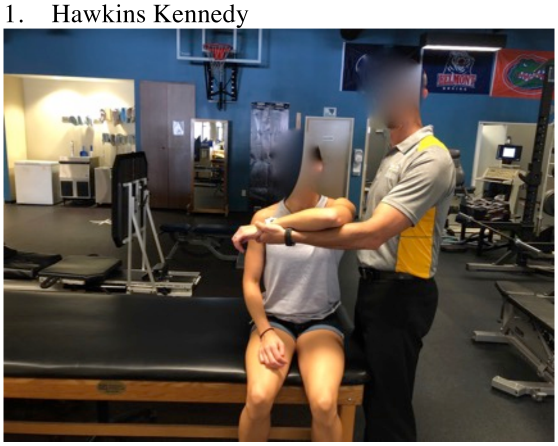


4. IR at 90_ of abduction and ER at 90_ of abduction

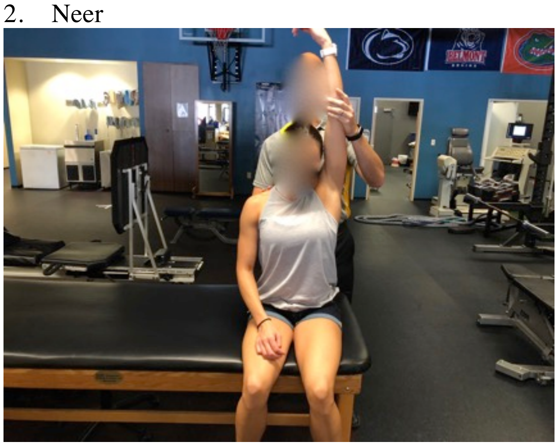
6. Myer's test horizontal adduction _

Special tests for the shoulder complex will be performed according to standard procedure:

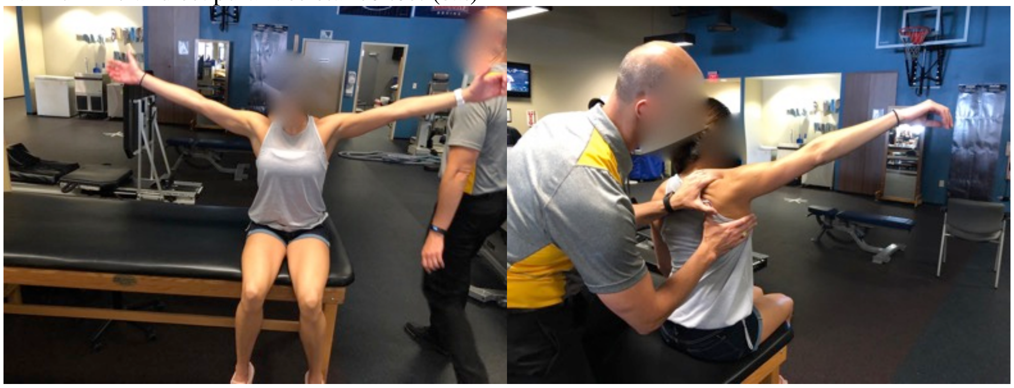
1. Hawkins Kennedy



2. Neer

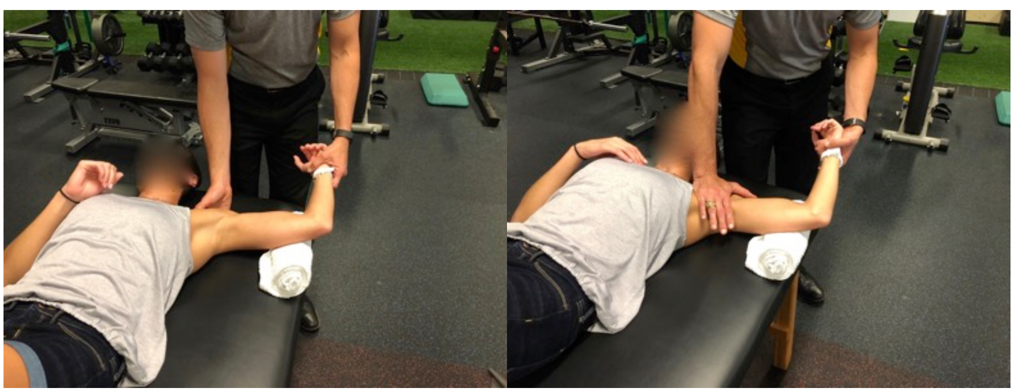


3. Painful Arc and scapular assistance test (sat)



4. Empty can and scapular reposition test (srt)

5. 90-90 ABER apprehension sign and Reduction/relocation test



6. Sulcus sign

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