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PIIA ANDSTEN

Shoulder injury prevention in youth tennis 12-16 years old

Exercise guide implemented as warmup for Ålk tennis club

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Abstract

Competing in tennis begins today at a young age and intensive sports specific training even earlier. This excessive focus on competing and intensive training at a young age may lead young players to injuries caused by overuse or trauma. The shoulder is prone to injury in tennis due to high loads and forces placed repeatedly on the joint. However, injuries in youth tennis may be prevented with appropriate training and warmup as well as being mentally and physically prepared for the upcoming training or match.

The aim of this thesis is to increase the knowledge of shoulder injury prevention in young tennis players and coaches. The objective of this thesis is to produce an exercise recommendation program for ÅLK tennis to be used as a warmup and to educate tennis players in the age group of 12-16 years and their coaches about preventative activity in tennis and the importance of a proper warm up.

The thesis was made in co-operation with Åbo Lawn-Tennis Klubb. Implementation of the thesis took part as an action-research and begun with collecting literature from which information was used to create the warmup guide. The target group was decided together with the tennis club based on the amount of junior tennis players.

The theoretical part of this thesis consisted of literature regarding shoulder injuries in youth tennis, biomechanics in tennis, anatomy of the shoulder girdle and injury prevention. In addition, general knowledge of important factors regarding the development and training of youth athletes were included.

Keywords
shoulder injuries, youth sports, biomechanics, injury prevention, youth development

CONTENTS

1 INTRODUCTION

Competing in tennis begins today at a young age and intensive sports specific training even earlier. This excessive focus on competing and intensive training at a young age may lead young players to injuries caused by overuse. (DiFiori et.al 2014). Sports injuries refer to sudden injuries that occur during physical activity. The number of sports injuries have also been steadily rising since the 1980´s. (Pasanen, Haapasalo, Halen & Parkkari 2021, 22).

During the growth spurts of young players, the number of injuries is increased as joints and growing bones are more susceptible for injury (Ahola et.al. 2019). In young athletes and/or players, the muscular and skeletal structures are still immature, therefore they are less resistant to tensile, shear and compressive forces during the rapid phases of growth. (DiFiori et.al 2014).

Considering the biomechanics of tennis, especially the serve, shoulders are susceptible to injury due to the dynamics and abnormal motion of the serve (Hoeven and Kibler, 2006; Roetert & Kovacs, 2020). Commonly, injuries in sports are caused by a clear chain of events and causes, therefore injury prevention is founded on understanding and identifying this chain and it´s components (Pasanen, Haapasalo, Halen & Parkkari 2021, 22)

Warmup is an essential aspect in sports to prepare the body and mind to upcoming training or game. Various exercises may easily be applied to warmup, thus assist developing multiple physical abilities. Warmup has also been studied play a role in injury prevention. (Steib et.al., 2017; Danskanen et. al., 2015; Pasanen, Haapasalo, Halen & Parkkari 2021; Andersson et. al., 2016).

2 AIM AND OBJECTIVE

The aim of this thesis is to increase the knowledge of shoulder injury prevention in young tennis players and coaches.

The objective of this thesis is to produce an exercise recommendation program for ÅLK tennis to be used as a warmup and to educate tennis players in the age group of 12-16 years and their coaches about preventative activity in tennis and the importance of a proper warm up.

3 TENNIS AS A SPORT

Tennis is a racket sport which was founded around the 1870's (Website of International Olympics committee, 2021). Tennis is played either individually or in doubles. The game is played on a rectangular field that is 23.77 m long and, for singles matches, 8.23 m wide. For doubles matches, the court is slightly wider and should be 10.97 m wide. (Website of ITF Rules of Tennis 2021, 2).

3.1 Scoring points

A tennis match can be played to the best of 3 sets or the bets of 5 sets. This means that a player or a pair needs to either win 2 sets to win the match or they need to win 3 sets to win the match. Points in a match are counted using sets and games. Sets can be scored using different methods which are “Advantage Set” and the “Tie-break Set”. These methods are used to determine the winner in deuce situation. Sets are scored using a four points method where points are counted in the following way: no point: “love” (0), first point (15), second point (30), third point (40) and fourth and final point is called “game”. (Website of ITF Rules of Tennis 2021, 5-6).

3.2 Tennis in Finland

The Finnish tennis association functions as a union for tennis in Finland. It was founded in 1911. The union consist of 150 tennis member clubs which consist of more than 25,000 members. In Finland approximately 130,000 people play tennis and 900,000 people are interested in tennis. (Website of Finnish tennis association, 2021).

4 SHOULDER GIRDLE ANATOMY AND FUNCTION

The shoulder is the human bodies most functional joint and structurally it the most complex joint. As the shoulder is the body´s most mobile joint, therefore it is also a relatively unstable joint due to its structure. (Kadi, Milants & Shahabpour, 2017; website of Physio-Pedia 2022). The nature of the shoulder joint allows for its versatile mobility. It allows for all movement directions, which are flexion and extension, abduction and adduction, circumduction, and internal and external rotation. (Chang, Anand & Varacallo, 2022; website of Physio-Pedia 2022; Agur & Dalley 2017).

Range of motion of the shoulder varies between individuals as it does in other joints. Normal ranges of motion in the shoulder are however considered to be the following: active flexion 160° to 190° and extension 60°to 70°, internal rotation 60° to 100° and external rotation 70° to 110°, adduction 50° to 75° and abduction 165° to 190°. (Reese & Bandy 2016, 58-77; Magee 2014, 271-275).

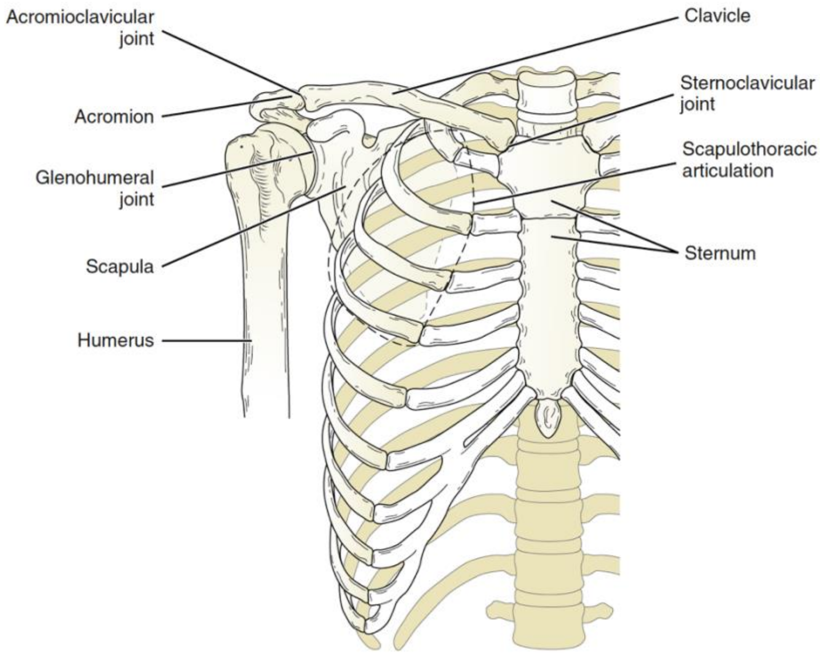
Stability of the glenohumeral joint is gained from both active and passive stabilizers. These consist of a set of muscles called the rotator cuff, the biceps tendon, ligaments as well as a fibrocartilaginous ridge which surrounds the glenoid cavity known as the glenoid labrum and the articular capsule of the glenohumeral joint. (Chang, Anand & Varacallo, 2022; Agur & Dalley 2017, 106-125; website of Physio-Pedia 2022).

4.1 Bones and joints of the shoulder complex

Bony structures of the shoulder girdle consist of the scapula, clavicle, and humerus which are seen in picture 1. Between these bones locate 4 joints which allow for the movements of the shoulder and upper arm. These four joints are called the glenohumeral joint, sternoclavicular joint, scapulothoracic joint and acromioclavicular joint. (Agur & Dalley 2017; website of physio-pedia, 2022; Reese & Bandy 2016).

The sternoclavicular joint is a synovial saddle joint which connects the appendicular skeleton to the axial skeleton. The acromioclavicular joint connects the acromion and the clavicle. Its primary function is to allow the scapula to adjust its position according to the arm movements. (Agur & Dalley 2017; website of physio-pedia, 2022).

The scapulothoracic joint anatomically is not considered to be a “true” joint, as it does not own common characteristics of a joint. It is the only “bone-to-bone” joint that connects the clavicle with the sternum. It functions to coordinate the arm movements with the thorax. (Agur & Dalley 2017; website of physio-pedia, 2022; website of kenhub, 2022).



Picture 1. Bones and joints of the shoulder complex (Reese & Bandy 2016, 48)

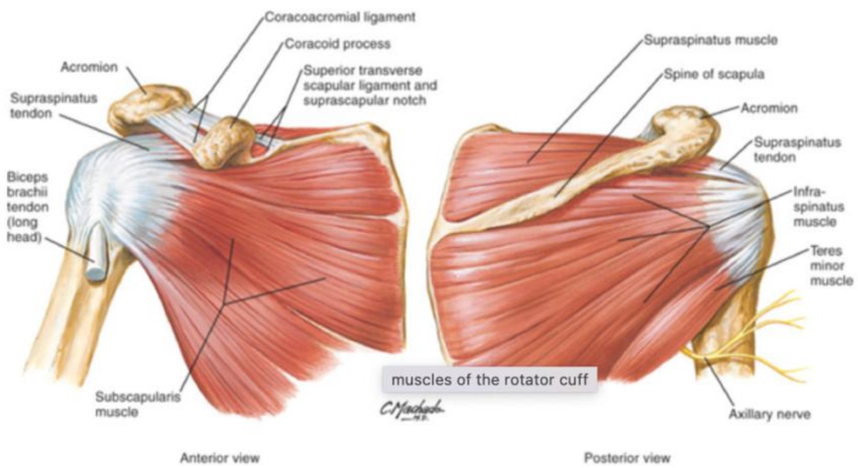
The glenohumeral joint is a ball-and-socket joint that connects the upper extremity to the axial skeleton. The connection occurs through the articulation of the humeral head and glenoid fossa of the scapula. The glenoid fossa is shallow; thus, it provides limited articular surface for the head of the humerus and therefore the glenohumeral joint is relatively unstable. The joint is characterized by three degrees of freedom of movement that were previously mentioned. (Reese & Bandy 2016; Magee 2014, 252; A. Miniato et. Al., 2021; website of physio-pedia, 2022).

Passive stability of the glenohumeral joint is provided by ligaments, the glenoid labrum, and the articular capsule. Dynamic stability of the joint is provided by the muscles surrounding the joint, primarily by the rotator cuff muscles. (Magee 2014, 252; website of Physio-pedia 2022; Kadi et.al., 2017).

4.2 Muscles of the shoulder girdle

The shoulder complex involves several muscles that provide both support and movement. Several muscles are involved in the shoulder and scapular movements, these are seen in pictures 2. and 3. The muscles of the shoulder can be divided into extrinsic and intrinsic muscles. The intrinsic muscles of the shoulder are the rotator cuff muscles and they are the primary source of support on the glenohumeral joint itself. (Website of physio-pedia, 2022).

The rotator cuff consists of four muscles: subscapularis, supraspinatus, infraspinatus, and teres minor (See picture 2). These four muscles form a musculotendinous cuff around the glenohumeral joint. The biomechanical role of the rotator cuff is to simply stabilize the glenohumeral joint by stabilizing the head of the humerus to the glenoid fossa. (Agur & Dalley, 2017; Chang, Anand & Varacallo, 2022; website of physio-pedia, 2022).

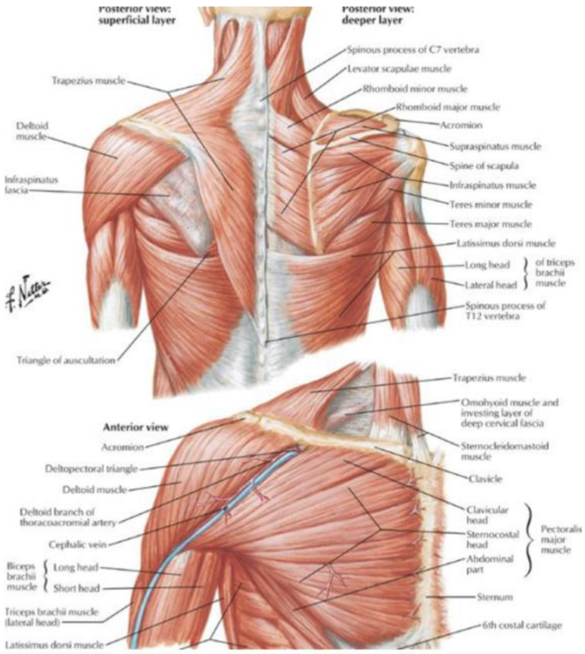


Picture 2. Muscles of the rotator cuff (website of fitness physio, 2022)

Flexion of the shoulder involves mainly the body’s anterior muscles which are the anterior aspect of the deltoid, pectoralis major, biceps brachii and coracobrachialis. The posterior musculature of the body is responsible for shoulder extension, and it involves the posterior aspect of the deltoid, latissimus dorsi, and teres major. (Chang, Anand & Varacallo, 2022; Sandström & Ahonen 2011).

Internal rotation is enabled by the subscapularis, pectoralis major, latissimus dorsi, teres major, and anterior aspect of the deltoid whereas external rotation involves primarily infraspinatus and teres minor (Agur & Dalley, 2017). Abduction is initiated by supraspinatus which is assisted by the medial part of the deltoid. Adduction is achieved primarily by pectoralis major, latissimus dorsi and teres major. (Sandström & Ahonen 2011; Agur & Dalley, 2017).

Scapulohumeral rhythm is a term used to describe the kinematic interaction of the scapula and the humerus. The movement and stability of the scapula are important factors in shoulder movement. Stabilizing and moving the scapula requires several muscles of which the primary stabilizers are the serratus anterior, rhomboid minor and major, levator scapulae, and the trapezius. (Paine & Voight, 2013; website of physio-pedia, 2022; Sandström & Ahonen 2011).



Picture 3. Muscles of the shoulder girdle (website of pediagenosis, 2022)

5 STROKES IN TENNIS AND BIOMECHANICS

The game of tennis has evolved over the years as well as equipment, therefore changes in stroke techniques have also occurred. Tennis is a versatile game and players are required strength, power, flexibility, and endurance. (Roetert & Kovacs, 2020; Roetert et al., 2009). Tennis consists of multiple different strokes: basic groundstrokes and special shots. The six basic strokes in tennis consist of the serve, forehand and backhand groundstrokes, forehand and backhand volley, and overhead smash. (Website of Tennis Companion, 2022). Strokes can be divided into separate phases that often include preparation, acceleration, point of contact, follow through. (Šlosar et. al., 2019; Roetert & Kovacs, 2020).

5.1 Groundstrokes forehand and backhand

Both forehand (see picture 4.) and backhand ground strokes may be hit from open, closed, and square stances. Stroke choices in tennis are situation dependent, which is simply explained by where the player is located on the court and what type of ball there are receiving. (Martin et. al. 2020; Roetert et.al. 2009; Luo, 2022).

5.1.1 Forehand

In today’s tennis, the open stance in the forehand is most often used, comparing to square or closed stance. The open stance stroke is characterized by the largest amount of rotation from the trunk, and thus it requires a lot of strength and flexibility from the core and lower extremities, which are required less in the closed and square stances. In the forehand stroke, as well as other strokes, high racket speed is developed by a chain of movements from the upper and lower extremities and the trunk rotation. Lower limbs mainly function in the sagittal plane. The trunk and upper limbs function in the horizontal plane. (Luo, 2022; Roetert & Kovacs, 2020).

The stroke begins with preparation which occurs through a backswing. Picture 4. demonstrates the preparation phase of an open stance forehand. Here the racket and shoulders are brought away from the net causing the muscles of the upper limbs to elongate. In this phase, loading of the lower limbs occurs to store power. Hip rotation in preparation is performed through eccentric contractions of the gastrocnemius and soleus, quadriceps, gluteal muscles, and the rotators of the hip. (Luo, 2022; Roetert & Kovacs, 2020).

Picture 4. Forehand preparation phase (website of Corralejo tennis, 2022)

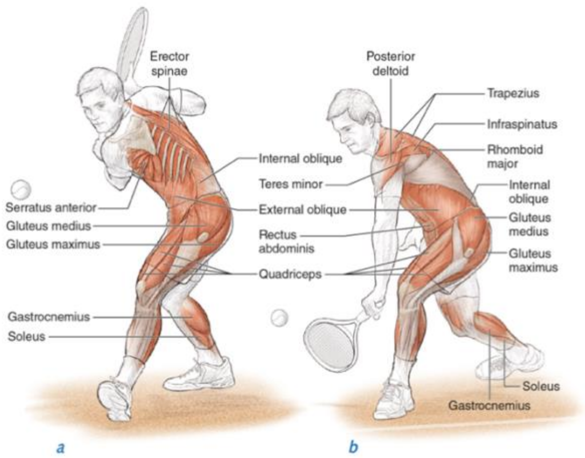
Preparation is followed by the forward swing and acceleration which begin when the racket is moved towards the net into contact with the ball. Here concentric and eccentric muscle actions occur again in the calf muscles, the quadriceps, gluteal muscles, and hip rotators to propel the lower limb movements and the rotation of the hip. Trunk rotation in this phase occurs through both concentric and eccentric muscle actions of both obliques, erector spinae and the extensors of the back. Finally, the racket is moved into ball contact through concentric muscle work from the latissimus dorsi, anterior deltoid, subscapularis, biceps, and pectoralis major. (Luo, 2022; Roetert & Kovacs, 2020).

The final stage of the stroke is the follow through. In this phase, deceleration occurs through lengthening contractions of the muscles. The muscles involved in arm deceleration are infraspinatus, teres minor, posterior deltoid, rhomboids, serratus anterior, trapezius, triceps, and wrist extensors. (Roetert & Kovacs, 2020).

5.1.2 Backhand

There are two different styles of backhand ground strokes in tennis: one-handed and twohanded backhand (see pictures 5. And 6.). Similar racket speeds may be achieved in either style of stroke. The backhand stroke has evolved greatly in tennis over last decades. The one-handed stroke used to be the most common option used around three decades ago, however in today's tennis the 2 handed backhand is seen to be more popular. (Roetert & Kovacs, 2020; Genevois et. al., 2015; Stepien et al., 2011).

The one-handed backhand (see picture 5.) is characterized with less trunk rotation, but the stroke requires well-coordinated actions of several body segments in the kinetic chain. In the preparation phase, lower limbs are loaded similarly as in the forehand stroke described previously. Trunk rotation in the one-handed backhand occurs through balanced concentric contractions of the internal and external obliques and lengthening of the erector spinae. (Roetert & Kovacs, 2020; Genevois et. al., 2015).



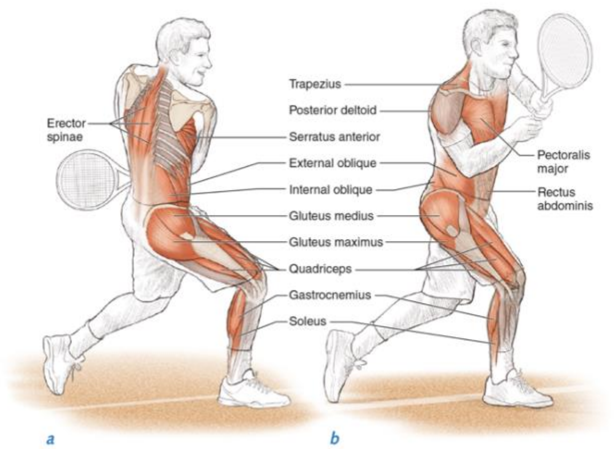
Picture 5. One handed backhand (Roetert & Kovacs, 2020)

The motion of the arm in the preparation of the swing involves concentric muscle actions of the deltoid (anterior aspect), wrist extensors, subscapularis, pectoralis major, and lengthening contractions of the posterior aspect of the deltoid, infraspinatus, trapezius, teres minor, serratus anterior and the rhomboids. The swing motions occurs similarly as described in the forehand strokes. Acceleration is performed through concentric contractions of the posterior aspect of the deltoid, infraspinatus, trapezius, and teres minor. The racket moves to ball contact through trunk rotation in the one-handed backstroke. Deceleration in the follow through phase requires the pectoralis major, biceps brachii, deltoid, subscapularis, and wrist flexors to contract concentrically. (Roetert & Kovacs, 2020; Genevois et. al., 2015).

Moving on to the two-handed backhand stroke. The two-handed stroke shares several similarities with the one-hand stroke but requires more rotation of trunk creating differences in the demands of the core muscles. The preparation phase requires the same muscles as the forehand and one-handed backhand preparation although racket grip and positions differ. Trunk and hip rotation in the two-handed backhand are more apparent compared with the onehanded stroke. The preparation requires concentric and eccentric contractions of the internal and external obliques, as well as lengthening of the erector spinae and abdominal muscles. (Roetert & Kovacs, 2020; Genevois et. al., 2015).

Rotation of the shoulder and arm on the non-dominant side are created by contractions of the infraspinatus, latissimus dorsi, deltoid, teres minor and wrist extensors and lengthening of pectoralis major and subscapularis. Moreover, on the dominant side, shoulder and arm movements are performed through the subscapularis, deltoid, wrist extensors and pectoris major contracting concentrically. In addition, eccentric contractions from the deltoid, rhomboids, trapezius, serratus anterior, infraspinatus and teres minor are needed. The two-handed backhand is seen to require 12% more rotation compared to the onehanded stroke. (Roetert & Kovacs, 2020; Genevois et. al., 2015).

In the two-handed backhand stroke (see picture 6.), the swing motion involves the same muscle actions as both strokes discussed previously. Both arms are responsible for bringing the racket into contact with the ball in the two-handed backhand stroke. Literature suggests that the dominant arm in the two-handed stroke functions to support the non-dominant arm whereas the non-dominant arm has a great role in creating horizontal racquet velocity when moving the racket into ball contact. (Roetert & Kovacs, 2020; Genevois et. al., 2015; Stepien et al., 2011). The deceleration phases in both backhands require different muscular eccentric contractions, however literature is lacking in the proper biomechanics and loads on the shoulder during a backhand stroke as well as how a risk of injury is present in backhand strokes (Roetert & Kovacs, 2020; Genevois et. al., 2015).



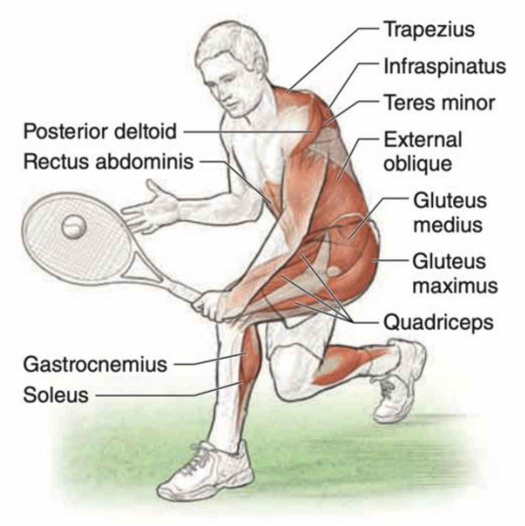
Picture 6. two handed backhand (Roetert & Kovacs, 2020)

5.2 Volleys

Volleys are strokes that are performed when the player in at the net or is approaching the net. In volleys the ball is shot from the air before it bounces on the court. There are several types of volleys, however here we only discuss the standard volley as it is mostly used. The overall racket movement is smaller in volleys when comparing to groundstrokes and the racket moves mainly forward and slightly downwards. (Furuya et al., 2021 & Roetert & Kovacs, 2020; website of Mouratoglou, 2022).

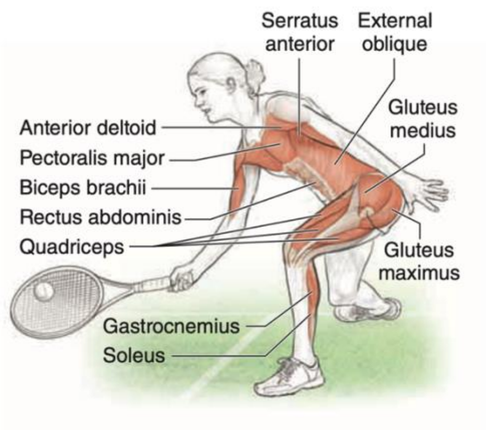
Volleys are characterized with similar lower limb movements as groundstrokes; however, volleys are performed in a more rapid speed and greater flexion and extension are required especially at the hips and knees. Weight transfer in volleys is assisted by a step forward if there is time as these aids in creating a more powerful volley. (Roetert & Kovacs, 2020; Furuya et al., 2021; website of Mouratoglou, 2022).

In both forehand and backhand (see picture 7.) volleys, preparation involves eccentric actions similar to the groundstrokes. Trunk rotation in the volleys requires the internal and external obliques to contract concentrically and lengthening of both obliques, erector spinae and the abdominals are needed. (Roetert & Kovacs, 2020).



Picture 7. Backhand volley (Roetert & Kovacs, 2020)

Now, in the forehand volley (see picture 8.) shoulder and arm rotation occurs through lengthening of the deltoid, subscapularis, and pectoralis major. Concentric contractions of deltoid, infraspinatus, teres minor, latissimus dorsi as well as wrist extensors are also required to rotate the shoulder and arm in the forehand volley. In the backhand volley, the eccentric and concentric muscle actions occur in exactly the opposite way to the forehand. (Roetert & Kovacs, 2020).



Picture 8. Forehand volley (Roetert & Kovacs, 2020)

Again, the forehand volley swing consists of similar muscle actions as ground strokes; shortening and lengthening occurs in the gastrocnemius, soleus, quadriceps, gluteal muscles. The hip rotators propel the legs motions and the hip rotation as they do in the groundstrokes. Trunk rotation in the volley occurs only approximately 20 to 25 degrees (comparing to the net) which is far more less when compared with the groundstroke. In the forehand volley, the racket moves to contact with the ball through contraction of the pectoralis major, latissimus dorsi, biceps brachii, deltoid and subscapularis. Vice versa, in the backhand, concentric actions are required from the posterior muscles (the trapezius, deltoid, teres minor and infraspinatus) to move the racket into contact with the ball. (Roetert & Kovacs, 2020; website of Mouratoglou, 2022).

Deceleration of the forehand volley occurs through eccentric muscle work. Muscles involved in deceleration of the forehand are the serratus anterior, triceps brachii, infraspinatus, rhomboids, teres minor, trapezius, and wrist extensors, whereas in the backhand, lengthening of the deltoid, biceps brachii, pectoralis major and subscapularis are required to decelerate the arm in follow through. (Roetert & Kovacs, 2020).

5.3 Serve and overheads

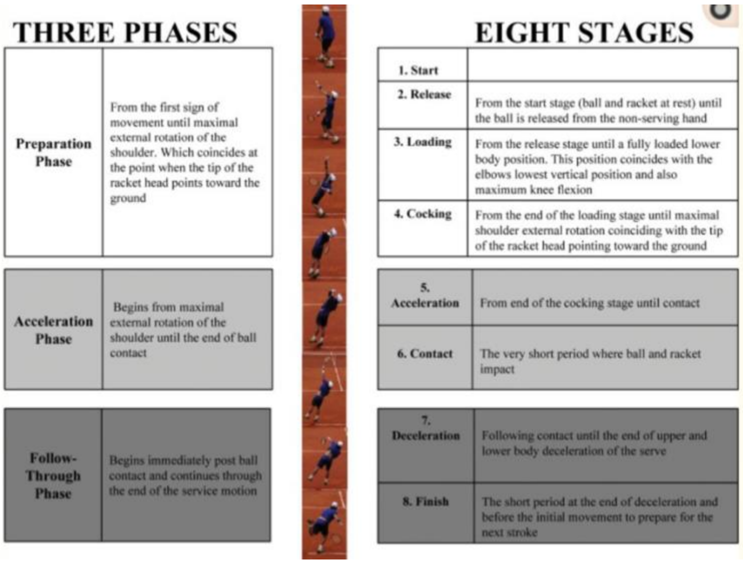
The serve is the first shot in a tennis game; thus, it is considered to be one of the most important shots in the game. The overhead motion of the serve shares similarities with the throwing motion in other overhead sports, such as baseball and volleyball. Due to this, biomechanical factors of the throwing motion may be applicable to several sports. (Abrams et. Al. 2014; Seminati et. Al. 2015).

Picture 9. Serve in tennis (website of Aspetar sports medicine journal, 2022)

A successful tennis serve or overhead is a result from a sum of forces and movements from the entire kinetic chain. The kinetic chain refers to the phenomenon of generating forces at one body segment and transferring that generated force to the next segment. In tennis, energy is initially generated at the feet and knees and then transmitted sequentially through the legs, trunk, back, shoulder, elbow, wrist, and hand, and finally to the racquet as in the previously discussed strokes. (Patel et. al., 2020; Dines et. al.2015; Roetert & Kovacs, 2020).

The serve is considered to be a complex motor skill due to the required coordination throughout the entire kinetic chain. A player should be able to utilize the entire kinetic chain to produce high amounts of power and thus increase racket speed which is eventually transferred to the ball. Power production in the serve and other tennis strokes begins at the lower limbs, which is followed by the trunk, from which it continues to the upper extremities through the shoulder and elbow all the way to the wrist from which the power is eventually transferred to the racket and ball. (Roetert & Kovacs, 2020; Trasolini et. al, 2020; Kovacs & Ellenbecker 2011; Šlosar, 2018; Colomar et. Al. 2022).

The tennis serve may be divided up to 8 different stages that are seen in picture 10. These 8 stages are commonly simplified into 3 main categories: loading, acceleration and follow through. The sets of movements in the serve may be seen and compared to the overhead motion in other sports, for example, the baseballers pitch as they share multiple similarities. (Roetert & Kovacs, 2020; Trasolini et. al, 2020; Kovacs & Ellenbecker 2011).



Picture 10. Phases of the tennis serve (Kovacs & Ellenbecker 2011)

In the loading phase of the serve, potential energy is stored and generated through knee flexion and rotation from the trunk. Within the preparation, when arm- cocking occurs just before acceleration, the upper extremity is positioned to its maximal external rotation. The maximal external rotation may be as much as 170 to 180 degrees of external rotation while maintaining approximately 90 to 100 degrees shoulder abduction, 90 to 100 degrees elbow flexion and 60 to 70 degrees of wrist extension. As the shoulder is positioned at maximal external rotation, the scapula is has positioned into maximal retraction, posterior tilt, and lateral rotation. (Roetert & Kovacs, 2020; Trasolini et. al, 2020; Kovacs & Ellenbecker 2011; Lin et. Al. 2018).

At the end stages of the arm-cocking acceleration begins. During the transition from arm-cocking to acceleration, forces and angular velocities on the shoulder are at the highest. The explosive vertical force during the acceleration phase is approximately 1.68 - 2.12 times the players body weight. (Lin et. al. 2018; Kovacs & Ellenbecker 2011). Strength and neuromuscular coordination are both required for proper power production in the serve and overheads. The primary accelerators of the serving arm are the pectorals, abdominals, quadriceps, and biceps brachii. (Roetert & Kovacs, 2020; Kovacs & Ellenbecker 2011). The acceleration motion is characterized by a corkscrew movement which occurs through a rapid lumbar spine rotation that changes direction from right lateral flexion and hyperextension (for a right-handed player) to hyperflexion and left lateral flexion. As the racket is brought to contact with the ball, the players trunk is in a tilted position of approximately 48° ± 7° degrees. (Kovacs & Ellenbecker 2011).

The follow through phase is the most demanding phase of the serve due to the large eccentric loads in the upper and lower limbs in deceleration. After ball contact the shoulder continues to internally rotate and the arm moves into pronation, which already has begun during the acceleration. The primary decelerators are the rotator cuff muscles, rhomboids, trapezius, and the back extensors. (Roetert & Kovacs, 2020; Kovacs & Ellenbecker 2011).

6 GENERAL DEVELOPMENT OF YOUTH

Children between the age of 10 to 17 experience numerous changes due to physical growth, biological maturing, and physiological development. Physical growth simply refers an increase in the size and proportions of body structures whereas biological maturation refers to the process of maturation (e.g., skeletal, somatic, sexual) towards a fully mature biological state. (Malina et. al., 2004, 4-7; Danskanen et. al., 2015). Furthermore, physiological development refers to the differentiation of the body's organ systems and structures and their functional development. Although physiological development is largely dependent on growth and maturation as well as other biological variables, the level of intellectual, social, moral, and emotional development influence on functional changes. Moreover, the environment and childhood physical activity have an impact in these changes. (Danskanen et. al., 2015).

Childhood height growth is at its slowest before the adolescent growth spurt occurs, therefore learning and developing motor skills at this phase of growth is rather easy. Growth at adolescence age is characterized by the pubertal growth spurt in height and weight. The acceleration of growth associated with adolescence begins earlier in girls than in boys, and thus the growth period of girls' is on average two years shorter than that of boys. (Cole, 2020; Danskanen et. al., 2015). During this stage of growth children increase considerably in size; girls grow on average 8 cm per year and boys 10 cm per year. (Williams et.al, 2021; Danskanen et. al., 2015; Cole, 2020). The intensity as well as timing of growth is variable, therefore children of the same chronological age may have large differences in size. The peak height velocity may occur already at the age of 10, but even at the age of 17. (Cole, 2020; Roelants & Cameron, 2022).

The nervous system develops greatly during childhood and has developed 80-90% of the adults' nervous system by the age of 6, therefore stimuli supporting development of motor skills and speed should be emphasized until early adolesce. Developing of these skills naturally must be continued even after reaching adolescence. (Danskanen et. al., 2015)

7 YOUTH TRAINING AND DEVELOPMENT

As discussed previously, several changes occur as a child enters adolescence. Sensitive periods of development are described as periods when certain characteristics develop partially through natural growth, therefore the development of that characteristic is effective during that time. In youth sports and in training it should be remembered that the individuals are changing constantly, thus it is critical to have appropriate training methods to prevent injuries that may be caused by overuse or overtraining. In addition, several different physical abilities are practiced in warmup today, thus it is relevant to know what forms of exercises are suitable to use in the warmups and training programs considering the growth phase of the young athletes. (Danskanen et. al., 2015; Pasanen, Haapasalo, Halen & Parkkari 2021; Steib et.al., 2017; McCary et. al., 2015).

7.1 Developing motor skills

Around the age of seven, children have acquired basic motor skills that include balance, coordination, postural control, and use of equipment etc. A child begins to learn specialized movement skills around the age seven when basic motor skills have mostly been already acquired. During adolescence, around the age of 15, individuals begin to utilize learned special motor skills. (Danskanen et. al., 2015)

7.2 Strength

Strength production is the basis for all movement and naturally all sports. Strength training aims to improve one’s ability to exert or resist force. Strength and resistance training can be carried out from childhood, but limitations related to growth and development of children should carefully be taken into account. (McDaniels et. al., 2009; Behm et.al. 2017; Danskanen et. al., 2015). According to literature, resistance training among youth aged 6 to 18 years seems to support improvements in muscular strength and power, dynamic balance, endurance, and generally their motor performance, thus support injury prevention. (Zwolski et. al. 2017, McDaniels et. al 2009; Kovacs et. al. 2008).

The absolute strength level in males develops rather linearly from the age of 6 to 12/14 years of age, after which strength development accumulates vigorously until the age of 20. (Danskanen et. al., 2015). In females, strength development before adolescence follows the same pattern, but differs when adolescence is reached. During adolescence females' strength development accumulates but occurs less vigorously due to the hormonal differences and lower muscle mass between the genders. (Danskanen et. al., 2015.)

7.3 Speed

The development of speed largely depends on the training potential created by the genetic inheritance and environmental factors, such as childhood exercise habits. Running speed develops at a similar pace in both sexes during childhood years. However, around the ages of around 11 to 15 years old, there occurs strong individual variation in speed development and the differences between the sexes seem to be growing. (Danskanen et. al., 2015). Maximum running speed develops approximately 3–4% yearly in both girls and boys. Reaction speed develops strongly during the ages of 6 and 10. Reaction speed is often fully developed as a child reaches puberty. Speed in general is dependent on proper functioning of the nervous system and energy metabolism; thus, muscles are required to be able to produce energy anaerobically. (Danskanen et. al., 2015).

Speed may be divided five categories: average speed, reactive speed, explosive speed, movement speed and speed skills. Average or basic speed refers to the neuromuscular systems overall ability to perform rapidly. Reaction speed refers to the time taken from the stimulus to the beginning of the movement and explosive speed refers to single movements performed at maximum speed. (Danskanen et. al., 2015). Movement speed is described as repeated cyclic movements performed as quickly as possible, such as running or swimming and speed skills refer to the neuromuscular systems ability to react quickly and purposefully in movements requiring skill, for example in ball games, such as tennis. (Danskanen et. al., 2015).

In early phases of puberty speed training should focus on developing factors mentioned previously, especially coordination, sense of rhythm, movement frequency, and elasticity. Games and relays are a great way to incorporate speed training in this phase of growth, but specific speed training components should be already moderately introduced during this growth phase. Recovery time should be 60-90 seconds at this stage. Although high-power jumping may be performed moderately at this stage, power in jumping should be kept around 70-90% as during this stage of development athletes are sensitive to stress injuries related to growth. The heel and lumbar spine are especially prone to injuries. (Danskanen et. al., 2015).

During the growth spurt speed training should focus on movement frequency and rhythm, as changes in body proportions during the growth spurt may have caused alterations to these skills. Movement skill and relaxation should also be emphasized during the growth spurt, so that the rapid change in height and weight would not weaken already learned motor skills. At this phase repetitions should be reduced and recovery time lengthened. (Danskanen et. al., 2015).

As the growth spurt has ended, speed training can be performed similarly with adult speed training. Here sports specific speed training is added, repetitions are reduced, and recovery time is increased. Upper and lower extremity plyometric exercises have been increasingly used as a part training programs and speed training as they have similar characteristics as the actual performances in the sport. Plyometric exercises in tennis are commonly focused in improving agility. (Danskanen et. al., 2015; Behm et. al. 2017; Ellenbecker et. al., 2015; Booth et. al., 2016).

7.4 Endurance

Tennis is a sport that requires endurance; thus, endurance training is necessary. General physical activity and overall condition have great importance in sports and training. Endurance training consist of sustained aerobic exercise that is performed with sufficient intensity, length, and frequency to improve aerobic fitness. (Danskanen et. al., 2015; Altermann & Gröpel, 2022; Armstrong & Barker, 2011).

Maximum endurance develops with 3 to 5 times of moderate intensity exercise (60-80% VO2max) a week which is performed regularly. Moderate intensity exercises should last at least 15 to 60 minutes. Alternatively, more demanding exercises may be performed in repeated rounds of short high intensity performances, such as sprints. (Danskanen et. al., 2015; Altermann & Gröpel, 2022). It is recommended that endurance type exercise is performed approximately 60 minutes a day (website of UKK-institute, 2022; Danskanen et. al., 2015).

7.5 Mobility

Several movements, especially in tennis, require sufficient mobility and flexibility to be performed. Sufficient joint mobility is important for general functional abilities, but also for athletic performances. Mobility (and flexibility) refers to the ability of a joint (and/or multiple joints) to move through unrestricted and pain free range of motion. (Danskanen et. al., 2015; website of physio-pedia, 2022).

Mobility can be divided into three categories which are active and passive mobility and anatomical range of motion. Active mobility refers to the range of motion achieved muscle work whereas passive mobility refers to the range of motion achieved through an external force, for example, gravity or another person. Anatomical range of motion is considered only as a concept, and it refers to the range of motion of a joint when the muscles are removed. (Danskanen et. al., 2015; website of physio-pedia, 2022).

During adolescence, mobility (and flexibility) improves if it is practiced. Exercises aiming to improve mobility consist of various methods of stretching. Active- dynamic stretching refers to stretching that consists of contractions of the antagonistic muscles. Active-static stretching refers to a stretching method where the stretching position is held for a period of time with the assistance of muscle work. Passive - dynamic stretching is a method of stretching where commonly assistance of another person is used and a short powerful stretch is performed repeatedly. (Kisner and Colby, 2017; Danskanen et. al., 2015; website of physio-pedia, 2022; Pasanen, Haapasalo, Halen & Parkkari, 2021).

Proprioceptive neuromuscular facilitation (PNF) is another method of stretching that is used to improve passive and active mobility. This method uses the stimulation of proprioceptors which are sensory cells that respond to body position and movement. There are various PNF techniques, however static stretching is the cornerstone to the PNF method. (Hindle et.al. 2012; Danskanen et. al., 2015; website of physio-pedia, 2022).

8 INJURIES IN TENNIS

Tennis is one of the most popular sports today and is highly physically demanding. The game is characterized by overhead motions, quick starts and stops with short explosive movements, and repetitive use of strokes and serves (Patel et. al., 2020; Kalo et.al. 2020; Dines et. al.2015).

Youth sports culture today is very different than it was 40 years ago; competing in sports is begun at a very young age and specializing in sports has increased in popularity, in hopes that elite levels are achieved. Specialization in sports occurs when an individual focuses mainly or even only in one sport. (Jayanthi et.al., 2019; Shannon et. al. 2020; DiFiori et.al 2014; Pasanen, Haapasalo, Halen & Parkkari 2021, 22.)

Studies have reported overuse injuries to be a common issue in youth tennis and generally in youth sports today. Young athletes have become more susceptible to overuse injuries due to the high training amounts and the repetitive stress. (Patel et. al., 2020; Kalo et.al. 2020; Dines et. al.2015; DiFiori et.al 2014; Zaremski et.al., 2019). Injuries in adolescent tennis players have been reported to occur at a rate of 1.2–2.8 injuries per 1,000 h played. Furthermore, the likelihood of second injury or repeated injury has been reported to be 31% after the occurrence of the first injury (Gescheit et al., 2019; Johansson et. al., 2022; Kovacs et al., 2014).

Upper extremity injuries in tennis and overhead sports have been increasingly studied in the recent years. Upper extremity injuries are shown to be the second most common type of injury in tennis and the prevalence of upper extremity injuries is approximately 20% to 49% of all injuries. (Pasanen, Haapasalo, Halen & Parkkari 2021, 394; Kovacs et al., 2014; Johansson et. al., 2022; Dines et. al.2015). The most frequently affected joints in upper extremity injuries have been reported to occur in the shoulder and elbow. (Patel et. al., 2020; Kalo et.al. 2020; Dines et. al.2015; Shannon et. al., 2020)

Injuries seen in upper extremities in tennis consist of internal impingement with associated rotator cuff and superior labral anterior to posterior (SLAP) lesions, scapular dyskinesia, lateral and medial epicondylitis, ulnar collateral ligament (UCL) tears, valgus extension overload (VEO), extensor carpi ulnaris (ECU) tendinosis and instability, and carpal stress injuries. Most common injuries related to the shoulder in tennis include internal impingement, SLAP- lesions, rotator cuff tears and scapular dyskinesia (Patel et. al., 2020; Kalo et.al. 2020; Dines et. al.2015; Pasanen, Haapasalo, Halen & Parkkari 2021; Shannon et. al., 2020; Gillet et. al. 2018; Kekelekis et. al., 2020)

8.1 Internal impingement

Internal impingement refers to a condition that is characterized by excessive and/or repetitive contact between the greater tuberosity of the humeral head with the posterior superior side of the glenoid as the arm is abducted and externally rotated. This position of the arm - that is seen, for example, in the tennis serve - ultimately leads to the impingement of the rotator cuff tendons and the glenoid labrum. (Patel et.al., 2020; Kekelekis et. al., 2020; Heyworth & Williams, 2009; Pasanen, Haapasalo, Halen & Parkkari 2021, 406–407; Dines et. al., 2015; Website of Physio-pedia, 2022).

8.2 Rotator cuff tears

In the overhead movements in tennis and in other strokes the rotator cuff muscles as well as ligaments have a great role in dynamically stabilizing the joint. Injuries in the rotator cuff are common in youth as well as adults. Possible causes leading to injuries or tears in the rotator cuff are overuse, often in sports involving overhead movements and issues due to biomechanics. (Website of physio-pedia, 2022; Patel et.al., 2020). Internal impingement of the shoulder and glenohumeral internal rotation deficiency (GIRD) may cause irritation and lead to tears or rips in the rotator cuff. (Pasanen, Haapasalo, Halen & Parkkari 2021, 406–407; Kalo et.al. 2020; Kekelekis et. al., 2020)

8.3 Superior labral anterior posterior (SLAP) lesion

Superior labral anterior posterior (SLAP) lesions refer to ruptures (or irritation) of the glenoid labrum. SLAP lesions occur at the superior glenoid labrum, where the long head of biceps tendon inserts. SLAP lesions are less seen in the youth population, but may still occur due to overuse, hyperextension, or trauma, which may occur in tennis. (Pasanen, Haapasalo, Halen & Parkkari 2021, 406–407; Kalo et.al. 2020; Dines et. al., 2015; Shannon et. al., 2020).

8.4 Scapular dyskinesia

Scapular Dyskinesia is not a specific issue of the shoulder but is greatly involved in shoulder injuries in sports involving overhead movements. Scapular Dyskinesia refers to the loss of normal scapular mechanics as well as position and alterations in scapular movement, which lead to functional deficiency, that in tennis may particularly be seen in the serve. As the scapula plays an important role in shoulder biomechanics, its dysfunctions have been associated with increasing the risk of shoulder injuries in overhead sports as much as 43%. Disruption in the kinetic chain of the serve and other strokes leads to compensatory mechanics, thus overloading other segments and causing an increased risk for injury. (Saini et.al., 2020; Shannon et. al., 2020; Pasanen, Haapasalo, Halen & Parkkari 2021, 422–423; website of physio-pedia, 2022).

9 INJURY PREVENTION

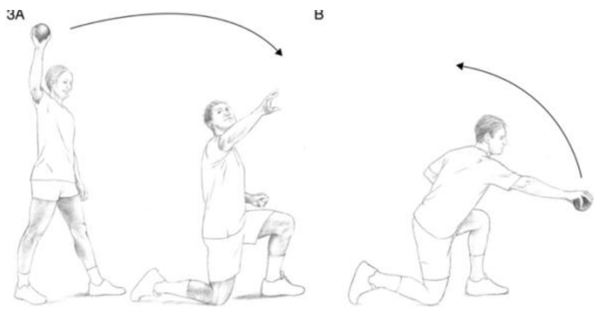
In the prevention of shoulder injuries occurring in tennis and other overhead sports, it is important for a physiotherapist to assess possible risk factors and identify possible mechanisms for shoulder injury (Pasanen, Haapasalo, Halen & Parkkari 202; Cools et.al., 2021; Wright et. al. 2021). Injury prevention may consist of, for example, warm up programs, strength, and mobility programs. However, recovery and nutrition are also important factors to consider in injury prevention. (Pasanen, Haapasalo, Halen & Parkkari 2021; Shannon et. al. 2020).

Generally, shoulder injury prevention should include glenohumeral and scapulothoracic muscle strengthening, ensuring adequate shoulder mobility, neuromuscular control, and dynamic stability of the shoulder. (Andersson, Bahr, Clarsen & Myklebust 2017; Dines et. al. 2015; Cools et. al. 2015; Andersson et. al., 2016).

Current evidence suggests that weakness or imbalances in muscle strength of external rotators are a risk factor for shoulder injuries. As discussed previously, disruption in scapular movements may cause increased risk of shoulder injury, thus scapular strength should also be kept in mind. Strengthening as well as range of motion exercises may be applied, for example, into warm up as a part of injury prevention. (Cools et. al., 2015; Cools et. al., 2021; Pasanen, Haapasalo, Halen & Parkkari 2021; Wright et. al. 2021; Andersson et. al., 2016).

As the rotator cuff muscles function as decelerators of the arm in, for example, the tennis serve, eccentric strengthening exercises have been recommended in literature. However, plyometric shoulder exercises have also been recommended as they share similar characteristics with actual movements in tennis. Pictures 11. and 12. represent two examples of eccentric and plyometric exercises. Plyometric exercises for the shoulder are often used in progressing from slow basic strength training to more demanding high speed power training. Plyometric exercises are commonly performed for approximately 30s, whereas other strengthening exercises have been performed with 15 to 20 repetitions. (Maenhout et. al. 2016; Cools et. al. 2015; Ellenbecker, 2009; Booth et. al., 2016).

Picture 11. Plyometric exercise for the shoulder (Kovacs, Roetert & Ellenbecker 2008).



Picture 12. Example plyometric exercise for the shoulder (Kovacs, Roetert & Ellenbecker 2008; Andersson et. al., 2016).

Picture 13. Eccentric exercise for external rotators (Cools et. al. 2015)

Adequate shoulder mobility is required to perform the versatile strokes in tennis. As GIRD represents a common issue in overhead sports today, studies have suggested that posterior capsular stretching may increase internal rotation of the shoulder. (Kalo et. al. 2020; Rose & Noonan, 2018; Pasanen, Haapasalo, Halen & Parkkari 2021, 51). Commonly used active stretches to seem to generally be performed as the sleeper stretch and the cross-body stretch, seen in picture 14. (Rose & Noonan, 2018; Cools et. al., 2015).

Picture 14. The sleepers stretch (Cools et. al., 2015)

It is supported by literature that overhead athletes develop adaptations to range of motion on their dominant shoulders. It has been demonstrated that the athlete’s dominant shoulder (compared with the nondominant shoulder) develops decreased internal rotation. (Kekelekis et. al., 2020; Keller et.al., 2018; Cools et.al., 2015; Andersson et. al. 2016). It has been suggested in literature that differences in internal rotation ROM of the dominant and non-dominant shoulder should be less than 18°, and the difference in total range of motion should be no more than 5°. Moreover, athletes with GIRD of > 25° in the dominant shoulder are approximately 4 times more likely for upper extremity injury. (Keller et.al., 2018; Cools et. al. 2015).

Injury prevention also includes monitoring sufficient training loads. With insufficient training in the long run, athletes become more prone to injuries as athletes' general condition does not meet with the requirements of the sport. However, large, and too sudden increases in training load are also seen as a risk for injury in sports. (Pasanen, Haapasalo, Halen & Parkkari 2021, 53; Danskanen et. al., 2015)

Warmup is an essential part of sports and exercise in general. Warmup before physical activity aims to prepare the athletes body for the upcoming training or game. Warmup is considered to enhance performance and be an essential part of injury prevention. (McCary et. al., 2015; Pasanen, Haapasalo, Halen & Parkkari 2021, 43; Danskanen et. al., 2015; Herman et. al., 2012; Alaya et. al., 2017).

Various studies have been made investigating the effects of different forms of warmups. Dynamic warmup and neuromuscular warmup seem to be favored more in today's sports. Neuromuscular training and warmup aim to improve cooperation of the nervous system and muscles. Neuromuscular training programs and warm up develops muscular strength, rapid power production, balance, dynamic stability of joints and movement control. (Steib et.al., 2017; McCary et. al., 2015; Pasanen, Haapasalo, Halen & Parkkari 2021; Andersson et. al., 2016).

Neuromuscular warmup often consists of movements specific to sports, strength and balance, flexibility, plyometric and, speed and agility exercises. The intensity of warmup is kept rather low and often are performed with body weight or light resistance. The length of warmup sessions commonly last approximately 15 to 20 minutes. (Andersson et. al., 2016; Alaya et. al., 2016; Pasanen, Haapasalo, Halen & Parkkari 2021, 51; Steib et.al., 2017; Fernandez-Fernandez et. al., 2020; Danskanen et. al., 2015, 320).

Literature on neuromuscular training and warmup have been conducted mostly focusing on lower limbs and team sports, however, research on neuromuscular training and warmup regimens focusing on upper extremities are still limited, although some research has been conducted on this area. The Oslo Sports Trauma research Centre has created an upper extremity warmup guide aiming for upper extremity injury prevention in overhead sports. This program has been studied to be effective in sports such as handball, which also includes overhead activities. This program shares similar movements that have been studied in literature previously and were previously represented in pictures 11. and 13. Neuromuscular training and warmup have been studied to be effective especially in lower limb injury prevention. In addition, neuromuscular and dynamic warmup seem to support performance enhancement in tennis. (Andersson et. al., 2016; Alaya et. al., 2016; Pasanen, Haapasalo, Halen & Parkkari 2021, 51; Steib et.al., 2017; Fernandez-Fernandez et. al., 2020; Alaya et. al., 2017; Herman et. al., 2012).

10 THESIS PROCESS

This thesis was implemented as an action-research thesis. The reason for choosing this method was to provide information in the warmup recommendation which consists of updated information about the topic. Theory of the thesis was based on the literature regarding injury prevention in youth sports and upper extremity injury epidemiology's in tennis.

10.1 Schedule

The schedule of the thesis can be seen in table 1. The thesis process began in autumn 2021 by choosing the topic. The author had interest in pediatric and musculoskeletal physiotherapy, thus brainstorming topics was a rather simple process. The original topic had to be narrowed down in the beginning of the thesis process due to the extent of sports injuries occurring in tennis in general and the age group. The age group was narrowed down into adolescence 12 to 16 years old as this age group had the highest number of participants in training in the ÅLK- tennis club. The decision-making process on the topic as well as product of the thesis was assisted by a meeting with the head coach of junior tennis in the ÅLK- tennis club and the supervising lecturer. Due to the strict times of training sessions, it was thought that the exercises would be useful to be implemented into warmup so that the juniors could possibly independently perform warmup before going to the court.

After presenting the thesis plan, the next step was to collect literature and deepen knowledge regarding the topic. Data collection and the writing process were continued until March 2022, after which the author had a long clinical practice during which the thesis process was paused for a while. The thesis process was delayed as the author was substituting a physiotherapist for 3 months after the clinical practice, therefore the writing of the thesis progressed slower than planned. The original plan was to present the thesis in October 2022, but this was changed to November 2022. Finally, the thesis was finished, and the thesis was presented in the end of November 2022.

Table 1. Schedule

Autumn 2021	Procude and present thesis plan + data collection
December 2021 & January 2022	collection of data
Spring 2022	data collection and writing thesis
Autumn 2022	Finish thesis and create manual
October & November 2022	Finish thesis and present thesis

10.2 Guide planning and implementation

The guide was made into a pdf file so that it is easy to use electronically and is printable. The font used in the warmup recommendation is times new roman as it is easy to read. Photos used in the guide consist of the authors self-taken photos as the author is familiar with the movements and the time limitations of the thesis process.

The guide includes recommendations relating to overall warmup. However, as the purpose of the guide is to introduce upper extremity warm up exercises, therefore only written instructions were given on the general warmup in addition to the upper body exercises. The written instructions included examples of general warmup exercises to be performed before moving on to the upper body specific exercises and recommendations on repetitions. Exercises chosen for the guide are tennis specific and require little equipment. Movements were also chosen so that they are easy to perform individually and don’t require a specific setting.

Piloting the product of the thesis was not considered necessary and possible due to the time limitations of the thesis process. The final product was sent to the head coach via email, thus making is easy to share to the players in the club.

11 DISCUSSION

The thesis process begun with deciding upon a topic. Choosing the topic related to youth sports and injury prevention, especially on shoulder injuries where rather clear from the very beginning due to the author's personal interest in this musculoskeletal structure, youth sports and the personal connection to the sport of tennis.

Without any previous knowledge or experience on overhead injuries especially in youth tennis, the thesis process as a whole has been a teaching and insightful experience to the author, as it has required growth in academic skills as well as flexibility, decision making and persistence. The author considers the overall thesis process to have supported her journey to becoming a physiotherapist. Although the thesis process schedule was planned well, unforeseen events occur in life and therefore, the schedule of the thesis had to be altered a few times.

Gathering literature on this topic was surprisingly easygoing to a certain extent as there is a large amount of research conducted on overhead sports injuries and injury prevention as well as warmup. However, finding literature on tennis specific shoulder injuries in youth age group and sports specific preventative measures was especially challenging. Moreover, the level of evidence in literature regarding several aspects of this topic appears versatile. Studies have established disagreements and overlapping's in different factors in causes and preventative measures of shoulder injuries in youth tennis and overhead sports in general.

The writing process took longer than expected and more topics were included than was originally planned in the beginning. Deeper familiarization into this topic made the author realize the extent of related issues there are that influence injuries and their prevention in youth tennis and sports. Several databases were used to obtain literature and theory of the topic. Main databases used consisted of Elsevier, Finna, PubMed, EBSCO host, google scholar and science direct. Several combinations of the search terms "youth sports", "shoulder injuries", "overhead sports", "injury prevention", "youth training", "tennis", "biomechanics" and "shoulder" were used to gather the literature. In addition, books were also used to gather initial data.

The warmup recommendation produced as a product of this thesis was delivered to the tennis club in an electrical form as agreed. The warmup recommendation production was begun as the author finished the writing process. The preparation of the guide was rather demanding as the author had no previous experience of creating one. Exercises used in the manual consisted of exercises found in literature and photos were self-taken by the author.

It should be noted that this thesis shows merely a scratch of knowledge regarding shoulder injuries, injury prevention, shoulder biomechanics in youth sports and tennis as well as youth training in general, thus this thesis only gives an overview of the factors and recommendations that were most apparent and agreed upon in the found literature.

For further investigation, it would be interesting to increase knowledge on what kind of tennis specific warmup and injury prevention programs are already in use and how they are applied in different age groups. It would also be interesting to know about the effectiveness of different injury prevention and warmup programs on youth sports injuries. As a lot of literature has been made on shoulder injuries on overhead motions, the author finds it interesting to learn more about the influence of biomechanics of other strokes in tennis and their impact on upper extremity injuries.

REFERENCES

Abrams, G., Harris, A., Andriacchi, T. & Safran, M. 2014. Biomechanical analysis of three tennis serve types using a markerless system. British Journal of Sports Medicine 48, 339-342. Referred 27.10.2020. http://dx.doi.org/10.1136/bjsports-2012- 091371.

Agur A. M. R. & Dalley A. F. (2017). Grant's atlas of anatomy (Edition 14). Wolters Kluwer.

Ahola, J-A., Vasankari, T., Nietosvaara, Y., Mattila, M. & Haara, M. 2019. Kasvuikäisten rasitusvammat. Duodecim 135, 1953-60. Referred 1.11.2021.

Andersson, S. H., Bahr, R., Clarsen, B., & Myklebust, G. (2016). Preventing overuse shoulder injuries among throwing athletes: A cluster-randomised controlled trial in 660 elite handball players. British Journal of Sports Medicine, 51(14), 1073–1080. https://doi.org/10.1136/bjsports-2016-096226

Andersson, S. H., Bahr, R., Clarsen, B., & Myklebust, G. (2017). Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players. British journal of sports medicine, 51(14), 1073–1080. https://doi.org/10.1136/bjsports-2016-096226

Ayala, F., Calderón-López, A., Delgado-Gosálbez, J. C., Parra-Sánchez, S., Pomares-Noguera, C., Hernández-Sánchez, S., López-Valenciano, A., & De Ste Croix, M. (2017). Acute Effects of Three Neuromuscular Warm-Up Strategies on Several Physical Performance Measures in Football Players. PloS one, 12(1), e0169660. https://doi.org/10.1371/journal.pone.0169660

Ayala, F., Moreno-Pérez, V., Vera-Garcia, F. J., Moya, M., Sanz-Rivas, D., & Fernandez-Fernandez, J. (2016). Acute and Time-Course Effects of Traditional and Dynamic Warm-Up Routines in Young Elite Junior Tennis Players. PloS one, 11(4), e0152790. https://doi.org/10.1371/journal.pone.0152790

Altermann, W., & Gröpel, P. (2022). Effects of acute endurance, strength, and coordination exercise interventions on attention in adolescents: A randomized controlled study. Psychology of Sport and Exercise, 102300. https://doi.org/10.1016/j.psychsport.2022.102300

Armstrong, N., & Barker, A. R. (2011). Endurance training and elite young athletes. The Elite Young Athlete, 59–83. https://doi.org/10.1159/000320633

Behm, D. G., Young, J. D., Whitten, J., Reid, J. C., Quigley, P. J., Low, J., Li, Y., Lima, C. D., Hodgson, D. D., Chaouachi, A., Prieske, O., & Granacher, U. (2017). Effectiveness of Traditional Strength vs. Power Training on Muscle Strength, Power and Speed with Youth: A Systematic Review and Meta-Analysis. Frontiers in physiology, 8, 423. https://doi.org/10.3389/fphys.2017.00423

Booth, M. A., & Orr, R. (2016). Effects of plyometric training on sports performance. Strength & Conditioning Journal, 38(1), 30–37. https://doi.org/10.1519/ssc.0000000000000183

Chang, L., Anand, P., & Varacallo, M. (2022). Anatomy, Shoulder and Upper Limb, Glenohumeral Joint. StatPearls. Treasure Island (FL): StatPearls Publishing; 2022. https://www.ncbi.nlm.nih.gov/books/NBK537018/

Cole T. J. (2020). Tanner's tempo of growth in adolescence: recent SITAR insights with the Harpenden Growth Study and ALSPAC. Annals of human biology, 47(2), 181–198. https://doi.org/10.1080/03014460.2020.1717615

Colomar, J., Corbi, F., Brich, Q., & Baiget, E. (2022). Determinant physical factors of tennis serve velocity: A brief review. International Journal of Sports Physiology and Performance, 17(8), 1159-1169. doi:10.1123/ijspp.2022-0091

Cools, A. M., Johansson, F. R., Borms, D., & Maenhout, A. (2015). Prevention of shoulder injuries in overhead athletes: a science-based approach. Brazilian journal of physical therapy, 19(5), 331–339. https://doi.org/10.1590/bjpt-rbf.2014.0109

Cools, A. M., Maenhout, A. G., Vanderstukken, F., Declève, P., Johansson, F. R., & Borms, D. (2021). The challenge of the sporting shoulder: From injury prevention through sport-specific rehabilitation toward return to play. Annals of Physical and Rehabilitation Medicine, 64(4), 101384. https://doi.org/10.1016/j.rehab.2020.03.009

Danskanen, K., Hakkarainen, H., Forsblom, K., Pulkkinen, S., & Pasanen, K. (2015). Lasten Ja Nuorten Hyvä Harjoittelu (1st ed.). VK-Kustannus Oy.

Difiori, J., P., Benjamin H., J., Brenner, S., J., Gregory A., Jayanthi N., Landry, G., L., & Luke, A. 2014. Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. Br J Sports Med 48, 287–288. Referred 1.11.2021. doi:10.1136/bjsports-2013-093299

Dines, J. S., Bedi, A., Williams, P. N., Dodson, C. C., Ellenbecker, T. S., Altchek, D. W., Windler, G., & Dines, D. M. (2015). Tennis injuries: epidemiology, pathophysiology, and treatment. The Journal of the American Academy of Orthopaedic Surgeons, 23(3), 181–189. https://doi.org/10.5435/JAAOS-D-13-00148

Ellenbecker, T. 2009. Application of upper extremity plyometrics for rehabilitation and performance enhancement on elite tennis players. http://www.thera-bandacademy.com/elements/clients/docs/Shoulder-Plyometrics-for-Tennis-Players-Ellenbecker-4-09__200904DD_093039.pdf

Ellenbecker, T., Pluim, B., Vivier, S. & Sniteman C. 2009. Common Injuries in Tennis Players: Exercises to Adress Muscular Imbalances and Reduce Injury Risk. Strength and Conditioning Journal. 31. https://journals.lww.com/nsca-scj/fulltext/2009/08000/common_injuries_in_ten- nis_players__exercises_to.6.aspx

Ellenbecker, T. S., Sueyoshi, T., & Bailie, D. S. (2015). Muscular activation during plyometric exercises in 90° of glenohumeral joint abduction. Sports health, 7(1), 75–79. https://doi.org/10.1177/1941738114553165

Fernandez-Fernandez, J., García-Tormo, V., Santos-Rosa, F. J., Teixeira, A. S., Nakamura, F. Y., Granacher, U., & Sanz-Rivas, D. (2020). The effect of a neuromuscular vs. dynamic warm-up on physical performance in Young Tennis Players. Journal of Strength and Conditioning Research, 34(10), 2776–2784. https://doi.org/10.1519/jsc.0000000000003703

Furuya, R., Yokoyama, H., Dimic, M., Yanai, T., Vogt, T., & Kanosue, K. (2021). Difference in racket head trajectory and muscle activity between the standard volley and the drop volley in tennis. doi: 10.1371/journal.pone.0257295

Genevois, C., Reid, M., Rogowski, I., & Crespo, M. (2015). Performance factors related to the different tennis backhand groundstrokes: a review. Journal of sports science & medicine, 14(1), 194–202.

Gillet, B., Begon, M., Diger, M., Berger-Vachon, C., & Rogowski, I. (2018). Alterations in scapulothoracic and humerothoracic kinematics during the tennis serve in adolescent players with a history of shoulder problems. Sports Biomechanics, 20(2), 165–177. https://doi.org/10.1080/14763141.2018.1526963

Heyworth, B. E., & Williams, R. J., 3rd (2009). Internal impingement of the shoulder. The American journal of sports medicine, 37(5), 1024–1037. https://doi.org/10.1177/0363546508324966

Herman, K., Barton, C., Malliaras, P., & Morrissey, D. (2012). The effectiveness of neuromuscular warm-up strategies, that require no additional equipment, for preventing lower limb injuries during sports participation: A systematic review. BMC Medicine, 10(1). https://doi.org/10.1186/1741-7015-10-75

Hindle, K. B., Whitcomb, T. J., Briggs, W. O., & Hong, J. (2012). Proprioceptive Neuromuscular Facilitation (PNF): Its Mechanisms and Effects on Range of Motion and Muscular Function. Journal of human kinetics, 31, 105–113. https://doi.org/10.2478/v10078-012-0011-y

Hoeven, H. V. D. & Kibler, W., B. 2006. Shoulder injuries in tennis players. British Journal of Sports Medicine 5, 435-440. Referred 2.11.2021. http://dx.doi.org/10.1136/bjsm.2005.023218

Jayanthi, N. A., Post, E. G., Laury, T. C., & Fabricant, P. D. (2019). Health Consequences of Youth Sport Specialization. Journal of Athletic Training, 54(10), 1040–1049. https://doi.org/10.4085/1062-6050-380-18

Johansson, F., Tranaeus, U., Asker, M., Skillgate, E., & Johansson, F. (2022). Athletic identity and shoulder overuse injury in competitive adolescent tennis players: The Smash Cohort Study. Frontiers in Sports and Active Living, 4. https://doi.org/10.3389/fspor.2022.940934

Kadi, R., Milants, A., & Shahabpour, M. (2017). Shoulder Anatomy and Normal Variants. Journal Of The Belgian Society Of Radiology, 101(S2), 3. doi: 10.5334/jbr-btr.1467

Kalo, K., Vogt, L., Sieland, J., Banzer, W., & Niederer, D. (2020). Injury and training history are associated with glenohumeral internal rotation deficit in youth tennis athletes. BMC Musculoskeletal Disorders, 21(1). https://doi.org/10.1186/s12891-020-03571-0

Kekelekis, A., Nikolaidis, P. T., Moore, I. S., Rosemann, T., & Knechtle, B. (2020). Risk factors for upper limb injury in tennis players: A systematic review. International Journal of Environmental Research and Public Health, 17(8), 2744. https://doi.org/10.3390/ijerph17082744

Keller, R. A., De Giacomo, A. F., Neumann, J. A., Limpisvasti, O., & Tibone, J. E. (2018). Glenohumeral Internal Rotation Deficit and Risk of Upper Extremity Injury in Overhead Athletes: A Meta-Analysis and Systematic Review. Sports health, 10(2), 125–132. https://doi.org/10.1177/1941738118756577

Kisner, C., Colby, L. A., & Borstad, J. (2017). Therapeutic exercise: foundations and techniques. Fa Davis.

Kovacs, M. S., Roetert, E. P., & Ellenbecker, T. S. (2008). Efficient deceleration: The forgotten factor in tennis-specific training. Strength & Conditioning Journal, 30(6), 58–69. https://doi.org/10.1519/ssc.0b013e31818e5fbc

Kovacs, M., & Ellenbecker, T. (2011). An 8-stage model for evaluating the tennis serve. Sports Health: A Multidisciplinary Approach, 3(6), 504–513. https://doi.org/10.1177/1941738111414175

Lin, D., Wong, T. & Kazam, J. 2018. Shoulder injuries in the overhead-throwing athlete: epidemiology, mechanisms of injury, and imaging findings. Radiology 286, 370-387. Referred 27.10.2020. https://doi.org/10.1148/radiol.2017170481.

Luo W. (2022). Biomechanical Analysis of Touch Ball Movements in Tennis Forehand Strokes. Computational intelligence and neuroscience, 2022, 5754820. https://doi.org/10.1155/2022/5754820

Maenhout, A., Benzoor, M., Werin, M., & Cools, A. (2016). Scapular muscle activity in a variety of plyometric exercises. Journal of Electromyography and Kinesiology, 27, 39–45. https://doi.org/10.1016/j.jelekin.2016.01.003

Magee, D. 2014. Orthopedic Physical Assessment. St.Louis: Elsevier Saunders.

Malina RM, Bouchard C, Bar-Or OEd. Growth, maturation and physical activity. Champaign, IL: Human Kinetics, USA; 2004.

Martin, C., Sorel, A., Touzard, P., Bideau, B., Gaborit, R., DeGroot, H., & Kulpa, R. (2020). Can the open stance forehand increase the risk of hip injuries in tennis players? Orthopaedic Journal of Sports Medicine, 8(12), 232596712096629. https://doi.org/10.1177/2325967120966297

McCrary, J. M., Ackermann, B. J., & Halaki, M. (2015). A systematic review of the effects of upper body warm-up on performance and injury. British Journal of Sports Medicine, 49(14), 935–942. https://doi.org/10.1136/bjsports-2014-094228

McDaniel, L., Jackson, A., & Gaudet, L. (2009). Strength Development for Young Adolescents. International Educational Studies, 2(3), 18-22. Retrieved from http://www.ccsenet.org/journal.html

Miniato, M., Anand, P., & Varacallo, M. (2021). Anatomy, Shoulder and Upper Limb, Shoulder. StatPearls Publishing LLC. https://www.ncbi.nlm.nih.gov/books/NBK536933/

Paine, R., & Voight, M. L. (2013). The role of the scapula. International journal of sports physical therapy, 8(5), 617–629.

Pasanen, K., Haapasalo, H., Halen, P. & Parkkari, J., 2021. Urheiluvammojen ehkäisy, hoito ja kuntoutus. Vk-kustannus.

Patel, H., Lala, S., Helfner, B., & Wong, T. T. (2020). Tennis overuse injuries in the upper extremity. Skeletal Radiology, 50(4), 629–644. https://doi.org/10.1007/s00256-020-03634-2

Reese, N. B., & Bandy, W. D. (2016). Joint range of motion and muscle length testing - e-book. Elsevier - Health Sciences Division.

Roelants, M., & Cameron, N. (2022). Adolescent growth. Human Growth And Development, 101-123. doi: 10.1016/b978-0-12-822652-0.00015-8

Roetert, E. P., Kovacs, M., Knudson, D., & Groppel, J. L. (2009). Biomechanics of the tennis groundstrokes: Implications for strength training. Strength & Conditioning Journal, 31(4), 41–49. https://doi.org/10.1519/ssc.0b013e3181aff0c3

Roetert, P., & Kovacs, M. (2020). Tennis anatomy (2nd ed.). Human Kinetics.

Rose, M. B., & Noonan, T. (2018). Glenohumeral internal rotation deficit in throwing athletes: current perspectives. Open access journal of sports medicine, 9, 69–78. https://doi.org/10.2147/OAJSM.S138975

Saini, S. S., Shah, S. S., & Curtis, A. S. (2020). Scapular Dyskinesis and the Kinetic Chain: Recognizing Dysfunction and Treating Injury in the Tennis Athlete. Current reviews in musculoskeletal medicine, 13(6), 748–756. https://doi.org/10.1007/s12178-020-09672-6

Sandström, M. & Ahonen, J. 2011. Liikkuva ihminen –aivot, liikuntafysiologia ja sovellettu biomekaniikka. Lahti: VK-Kustannus Oy

Seminati, E., Marzari, A., Vacondio, O., & Minetti, A. E. (2015). Shoulder 3D range of motion and humerus rotation in two volleyball spike techniques: Injury prevention and performance. Sports Biomechanics, 14(2), 216–231. https://doi.org/10.1080/14763141.2015.1052747

Shannon, N., Cable, B., Wood, T., & Kelly, J. (2020). Common and less well-known upper-limb injuries in elite tennis players. Current Sports Medicine Reports, 19(10), 414–421. https://doi.org/10.1249/jsr.0000000000000760

Šlosar, L., Šimunič, B., Pišot, R., & Marusic, U. (2018). Validation of a tennis rating score to evaluate the technical level of children tennis players. Journal of Sports Sciences, 37(1), 100-107. doi:10.1080/02640414.2018.1483184'

Steib, S., Rahlf, A. L., Pfeifer, K., & Zech, A. (2017). Dose-response relationship of neuromuscular training for injury prevention in youth athletes: A meta-analysis. Frontiers in Physiology, 8. https://doi.org/10.3389/fphys.2017.00920

Stępień, A., Bober, T., & Zawadzki, J. (2011). The kinematics of trunk and upper extremities in one-handed and two-handed backhand stroke. Journal of human kinetics, 30, 37–47. https://doi.org/10.2478/v10078-011-0071-4

Trasolini, N., Nicholson, K., Mylott, J., Bullock, G., Hulburt, T., & Waterman, B. (2022). Biomechanical Analysis of the Throwing Athlete and Its Impact on Return to Sport. Arthroscopy, Sports Medicine, And Rehabilitation, 4(1), e83-e91. doi: 10.1016/j.asmr.2021.09.027

Williams, M. D., Ramirez-Campillo, R., Chaabene, H., & Moran, J. (2021). Neuromuscular training and motor control in youth athletes: A meta-analysis. Perceptual and Motor Skills, 128(5), 1975–1997. https://doi.org/10.1177/00315125211029006

Wright, A. A., Ness, B. M., Donaldson, M., Hegedus, E. J., Salamh, P., & Cleland, J. A. (2021). Effectiveness of shoulder injury prevention programs in an overhead athletic population: A systematic review. Physical Therapy in Sport, 52, 189–193. https://doi.org/10.1016/j.ptsp.2021.09.004

Zaremski, J. L., Zeppieri, G., Jr, & Tripp, B. L. (2019). Sport Specialization and Overuse Injuries in Adolescent Throwing Athletes: A Narrative Review. Journal of athletic training, 54(10), 1030–1039. https://doi.org/10.4085/1062-6050-333-18

Zwolski, C., Quatman-Yates, C., & Paterno, M. V. (2017). Resistance Training in Youth: Laying the Foundation for Injury Prevention and Physical Literacy. Sports health, 9(5), 436–443. https://doi.org/10.1177/1941738117704153

The website of Aspetar sports medicine journal. Retrieved 26.10.22 https://www.aspetar.com/journal/viewarticle.aspx?id=198#.Y1lvGC0RpN1

The website of Corralejo Tennis. Referred to 27.10.2022 https://www.corralejotennis.com/2015/06/11/open-stance-vs-closed-stance-forehands/

The website of Finnish tennis association. Referred to 10.12.2021 https://www.tennis.fi

The website of International Olympics committee. Referred to 20.11.2021 https://olympics.com/ioc/overview

The website of the International Tennis Federation. Referred to 10.12.2021 https://www.itftennis.com/media/4421/2021-rules-of-tennis-english.pdf

The website of Fitnessphysio. Referred 12.10.2022 https://www.fitnessphysio.com/rotator-cuff-tears

The website of Kenhub. Referred to 20.10.2022 https://www.kenhub.com

The website of Mouratoglou. Referred to 2.11.2022 https://www.mouratoglou.com/

The website of Pediagenosis. Referred to 12.10.2022 https://www.pediagenosis.com/2019/06/muscles-of-shoulder-anatomy.html

The website of Physio-Pedia. Referred to 2.11.2022 https://www.physio-pedia.com/home/

The website of Tennis companion. Referred to 30.9.2022 https://tenniscompanion.org