

To Evaluate the Factors that Affect the Rates of Muscle Injury, Rehabilitation & Recovery, with a Focus on Common Shoulder & Knee Injuries Found in Swimmers

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Abstract: *The aim of my research project was to evaluate the factors that affect the rates of muscle injury, rehabilitation & recovery, with a focus on common shoulder & knee injuries found in swimmers. As a competitive swimmer for over a decade, I have realized that injuries are inevitable in any athlete's life, however there are multiple factors that influence the probability of one. While I was training at the Padukone-Dravid Center of Sports Excellence, I was suffering with shoulder and back pain. My head coach, Mr. Nihar Ameen, introduced me to the Abhinav-Bindra Targeting Performance (ABTP), an advanced physiotherapy and rehabilitation center installed with technological devices from around the world that heavily depend on data driven analysis to deliver accurate measurements of relevant parameters of the musculoskeletal performance of an individual. A biomechanist conducted a biomechanical assessment to deduce the cause of the pain and identify other weak regions in my body. After rehabilitation and recovery, my performance in both the pool and gym improved. I was interested to learn about the science and biomechanics behind this recovery, as well as the factors that affect it.*

Keywords: Muscle Injury, Rehabilitation, Recovery, Shoulder, Knee

1. Background Information about Swimming

“Swimming is a unique sport that combines upper and lower extremity strength exercises with cardiovascular training in a non-weight bearing environment.”¹

Competitive swimming includes 4 different strokes which are Freestyle, Breaststroke, Butterfly and Backstroke. Usually, each competitive swimmer has one or two main strokes in which they compete, however, the majority of our training time is spent doing Freestyle.

Swimming is considered one of the most difficult sports for 5 sole reasons, which include mastering the technique of each stroke, water resistance, the intensity of exercise on land, year-round training commitment, and the goal of increasing speed by reducing time.

Stamina, endurance and strength can only help a swimmer to a certain extent. Beyond that, every swimmer relies on a strong, close-to-perfect technique to swim faster. A better technique indicates a greater ability to glide through the water, minimizing the effect of water resistance. Water has a greater density than air, which makes it more difficult for someone to move through the water. To cut through the water efficiently, swimmers are required to produce force while maintaining a lean body structure. An excess in muscle creates extra weight and volume for the swimmer, which causes more drag and resistance in the water. Hence,

the training done on land needs to be altered accordingly to form lean muscle that still provides strength. Unlike most sports, competitive swimmers train all year round without any off-season. My experience over the years has taught me that taking one day of rest can set me two days behind in training. Competitive swimmers are constantly striving to reduce their time. The difference in time between the Olympic medalists for the 50m Freestyle race was less than half a second.²

Due to the level of intensity of the sport, warming up and cooling down is vital to minimize the risk of injuries.³ Warming up prepares the body for aerobic and anaerobic activity while cooling down ensures a gradual recovery of heart rate and blood pressure.

Injuries in Swimmers

A study conducted over 5 years by the National Collegiate Athletic Association (NCAA) concluded that the overall injury rates per 1000 training sessions were estimated as 4.00 for men and 3.78 for women.⁴

Another study to estimate the “prevalence of musculoskeletal pain in competitive male swimmers, and to

¹Wanivenhaus, Florian, et al. “Epidemiology of Injuries and Prevention Strategies in Competitive Swimmers.” *Sports Health: A Multidisciplinary Approach*, vol. 4, no. 3, 6 Apr. 2012, pp. 246–251, www.ncbi.nlm.nih.gov/pmc/articles/PMC3435931/, 10.1177/1941738112442132. Accessed 29 Oct. 2021.

²IOC. “Tokyo 2020 Men's 50m Freestyle Results-Olympic Swimming.” *Olympics.com*, 2020, olympics.com/en/olympic-games/tokyo-2020/results/swimming/men-s-50m-freestyle. Accessed 29 Oct. 2021.

³Mayo Clinic. “The Right Way to Warm up and Cool Down.” *Mayo Clinic*, 9 July 2019, www.mayoclinic.org/healthy-lifestyle/fitness/in-depth/exercise/art-20045517#:~:text=A%20warmup%20gradually%20revs%20up. Accessed 29 Oct. 2021.

⁴Wolf, Brian R., et al. “Injury Patterns in Division I Collegiate Swimming.” *The American Journal of Sports Medicine*, vol. 37, no. 10, 24 July 2009, pp. 2037–2042, 10.1177/0363546509339364.

investigate the relationship between stroke style and musculoskeletal pain” found that 60% of the swimmers reported some form of musculoskeletal pain. The results showed that 13 had shoulder pain, 7 had lower back pain, and 3 had knee pain.

Hence, I chose to delve deep into the anatomy and epidemiology of injuries in the shoulders and knees.

Anatomy and Epidemiology of Shoulder Injuries in Swimmers

Structure and Function of the shoulder:

The human shoulder is the most mobile joint in the body, which enables a large range of motion in a variety of planes. The shoulder contains a **shoulder girdle** which is made up of four articulations (joints). These are sternoclavicular joints (SC), acromioclavicular joints (AC), glenohumeral joints, and scapulothoracic joints. It also consists of three bones-the clavicle, scapula, and humerus.⁵

Articulations in the Shoulder girdle

The **Sternoclavicular** joint is the only joint that connects the upper limb to the axial skeleton. The **Acromioclavicular** (AC) joint attaches the scapula to the thorax, allowing an additional range of motion to the scapula. The **Glenohumeral** joint is a ball-and-socket joint that allows complex, dynamic movement between the glenoid of the scapula and the proximal humerus. The **Scapulothoracic** joint allows for complex scapular movements concerning the thoracic cage.⁶

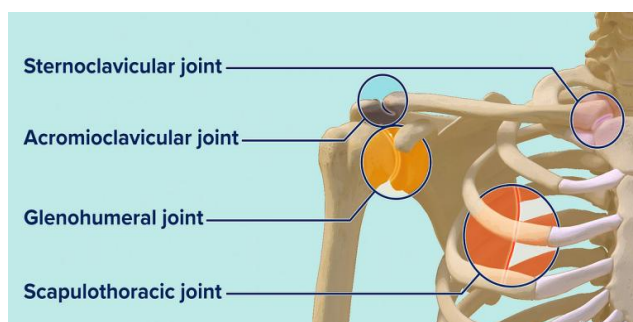


Image 1: The articulations in the shoulder girdle

The Bones of the Shoulder

The **Scapula** bone functions as the site for muscular attachment. Four rotator cuff muscles begin here. These muscles are the Supraspinatus, Infraspinatus, Teres minor, and Subscapularis. Other muscles such as the trapezius, serratus anterior, rhomboids, and Levator scapulae inserted on the scapula are responsible for scapular mobility and stability.

The **Clavicle** (collarbone) is a long and thin bone located between the shoulder and the top of the rib cage that forms

⁵Miniato, Mohammed A., et al. "Anatomy, Shoulder and Upper Limb, Shoulder." *PubMed*, StatPearls Publishing, 2022, www.ncbi.nlm.nih.gov/books/NBK536933/#:~:text=Four%20joints%20are%20present%20in. Accessed 29 Oct. 2021.

⁶MD, David Novak. "Guide to Shoulder Anatomy." *Sports-Health*, 13 June 2019, www.sports-health.com/sports-injuries/shoulder-injuries/guide-shoulder-anatomy.

Accessed 29 Oct. 2021.

the front portion of the shoulder girdle. It keeps the arm away from the torso, allowing free movement. The clavicle also protects the important underlying veins, arteries, and nerves in the front and back of the structure. It consists of the SC joint and the AC joint.

The **Humerus** is the bone of the upper arm. The humeral head, which is the top portion of the bone, fits into the **Glenoid cavity** which is the shallow socket of the scapula, creating the shoulder's ball-and-socket joint. This allows for the arm's large range of motion.⁷

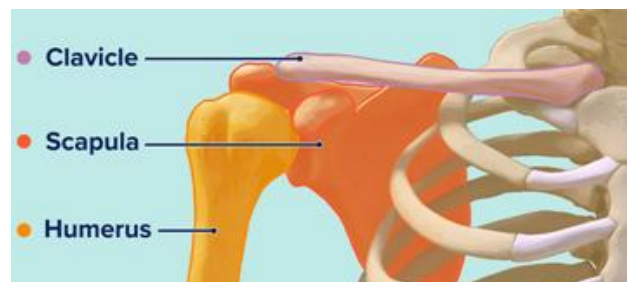


Image 2: The bones of the Shoulder

Soft Tissue in the shoulder:

Subacromial Bursa/Subdeltoid Bursa: the bursa is a fluid-filled sac that acts as a shock-absorbing cushion, reducing the friction during and movement of the shoulder. It often extends out to be continuous with the subdeltoid bursa.

Glenoid labrum: It is a fibrocartilaginous tissue within the glenoid cavity of the shoulder joint. Its function is to provide stability and shock absorption within the joint.

Movements of the Shoulder:

Anterior means the front of the body while posterior means towards the back. Lateral means to the side of the body or away from the middle of the body. Medial means toward the middle or centre of the body.

A few major movements of the glenohumeral joint (a ball-and-socket joint) are

- **Abduction**-the upward lateral movement of the Humerus in the plane of the scapula
- **Adduction**-the downward medial movement of the humerus in the plane of the scapula
- **Flexion**-the movement of the Humerus straight anteriorly
- **Extension**-the movement of the Humerus straight posteriorly
- **External rotation**-the movement of the Humerus laterally around its long axis
- **Internal rotation**-the movement of the Humerus medially around its long axis
- **Horizontal adduction**-also known as transverse flexion, the movement of the Humerus in a horizontal or transverse plane towards and across the chest

⁷"Shoulder Anatomy." *Jacksonville Orthopaedic Institute*, www.joionline.net/trending/content/shoulder-anatomy. Accessed 29 Oct. 2021.

- **Horizontal abduction**-also known as transverse extension, the movement of the Humerus in a horizontal or transverse plane away from the chest

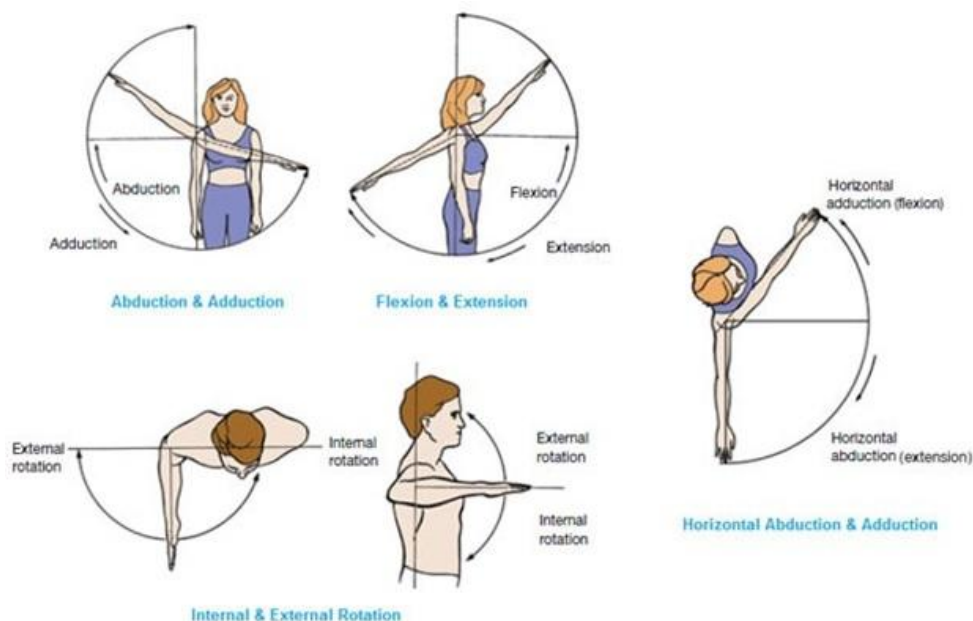


Image 3: Movements of the Shoulder

(Muscles That Move the Arm." *Www.acefitness.org*, www.acefitness.org/fitness-certifications/ace-answers/exam-preparation-blog/3535/muscles-that-move-the-arm/. Accessed 29 Oct. 2021)

Shoulder Muscles

Intrinsic shoulder muscles of the shoulder connect the scapula and or clavicle to the humerus. These muscles include the Deltoid, Teres major, Rotator cuff muscles (supraspinatus, infraspinatus, teres minor, and subscapularis), Trapezius, Latissimus Dorsi, Levator scapulae, Rhomboid major, Rhomboid minor, Serratus anterior, Pectoralis major, Pectoralis minor, Subclavius, Coracobrachialis, Biceps brachii and Triceps brachii. Different shoulder muscles are used to different extents for different strokes, elaborated in the next section.

Epidemiology of Shoulder Injuries

Competitive swimmers swim approximately 14,000m every day, which results in around 2500 shoulder revolutions each session, and 16,000 every week.⁸ Unlike most other sports which use leg strength to generate a propulsive force, swimming primarily utilizes upper body strength. Approximately 90% of the forward thrust is provided by the torque generated from the shoulder.⁹ The overuse of the shoulder muscles results in the shoulder joint being subjected to repetitive microtrauma. Repetitive microtrauma is "repeated exposure of the musculoskeletal tissue to low-magnitude forces" which results in injuries at the microscopic level.¹⁰ Hence, shoulder pain is the most

frequent orthopaedic injury in swimmers, with a reported prevalence between 40% and 91%

Swimmer's shoulder

"Swimmer's shoulder is a musculoskeletal condition that results in symptoms in the area of the anterior lateral aspect of the shoulder, sometimes confined to the subacromial region."¹¹

Coined by Kennedy and Hawkins, it was initially assumed that the cause of the pain was the impingement of the rotator cuff tendons. However, with further analysis of shoulder pain, the cause was revealed as multifactorial. These include stroke biomechanics; overuse and fatigue of the shoulder, scapula and upper back; glenohumeral laxity with subsequent shoulder instability

Common injuries under Swimmer's Shoulder

- Superior Labrum, Anterior to Posterior tears (SLAP tear)
- Supraspinatus tendinitis
- Bicipital tendinitis
- Rotator cuff injuries
- Bursitis
- AC Joint injury
- Shoulder impingement

Stroke Biomechanics

An incorrect stroke or repeated incorrect movements of a particular stroke could lead to "swimmer's shoulder". Since

⁸Tavares, Nuno, et al. "Effectiveness of Therapeutic Exercise in Musculoskeletal Risk Factors Related to Swimmer's Shoulder." *European Journal of Investigation in Health, Psychology and Education*, vol. 12, no. 6, 2 June 2022, pp. 601-615, 10.3390/ejihpe12060044. Accessed 12 Aug. 2022.

⁹Davis, Donald, et al. "Swimmer's Shoulder." *StatPearls*, 4 Sept. 2022,

www.statpearls.com/ArticleLibrary/viewarticle/29789. Accessed 29 Oct. 2021.

¹⁰Kannus, P. "Etiology and Pathophysiology of Chronic Tendon Disorders in Sports." *Scandinavian Journal of Medicine & Science in Sports*, vol. 7, no. 2, 30 Jan. 2007, pp. 78-85,

onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-0838.1997.tb00123.x, 10.1111/j.1600-0838.1997.tb00123.x. Accessed 8 Feb. 2019.

¹¹Tovin, Brian J. "Prevention and Treatment of Swimmer's Shoulder." *North American Journal of Sports Physical Therapy : NAJSPT*, vol. 1, no. 4, 1 Nov. 2006, www.ncbi.nlm.nih.gov/pmc/articles/PMC2953356/#:~:text=Stroke%20power%20is%20achieved%20through. Accessed 29 Oct. 2021.

the biomechanics of each stroke are different, the injuries are a result of the requirements of the stroke. The biomechanics of the strokes are illustrated below.

Freestyle

Freestyle consists of different phases and requires a combined movement of scapular retraction and elevation with humeral abduction and external rotation during the stroke recovery. The initial pull-through phase causes the protraction of the scapula while the humerus is adducted, extended, and internally rotated. The stroke is more powerful through the shoulder adductors, extenders, and internal rotators with the serratus anterior and latissimus dorsi acting as key propulsion muscles. Internal rotation and horizontal adduction also take place.

Butterfly

The movement in this stroke is similar to freestyle at the shoulder, but the stress exerted on the muscles is different because both arms simultaneously move through the same motion. This indicates no movement of the trunk, hence the demand of the medial scapular stabilizers and retractors during recovery is greater as compared to freestyle. The humeral head moves into a position of elevation, horizontal adduction and internal rotation at hand entry.

Backstroke

The shoulder motion in backstroke is opposite to freestyle, with the shoulder in retraction, horizontal abduction and external rotation at hand entry and the beginning of the pull-through. This increases the stress on the anterior capsule. The elbow is extended.

Breaststroke

This stroke has a different shoulder motion as compared to the other three strokes. Like butterfly, arms are moved simultaneously through a motion that initiates in complete flexion with internal rotation. The elbows remain fixed during the pull-through until the humerus is completely adducted and brought to horizontal adduction with the forearms touching each other. (Prevention and Treatment of Swimmer’s Shoulder.” *North American Journal of Sports Physical Therapy : NAJSPT*, vol. 1, no. 4, 1 Nov. 2006, www.ncbi.nlm.nih.gov/pmc/articles/PMC2953356/#:~:text=Stroke%20power%20is%20achieved%20through. Accessed 29 Oct. 2021.)

Muscles Used and Fatigue

Since the shoulder is an inherently unstable joint, muscle forces are critical for maintaining stability, painless function and efficient motion. (De Martino, Ivan, and Scott A. Rodeo. “The Swimmer’s Shoulder: Multidirectional Instability.” *Current Reviews in Musculoskeletal Medicine*, vol. 11, no. 2, 20 Apr. 2018, pp. 167–171, 10.1007/s12178-018-9485-0)

The greatest propulsive force in the water is generated by the adduction and internal rotation of the upper extremities, using two major muscles-**Pectoralis major** and **Latissimus dorsi**. The training-induced adduction and internal rotation strength in swimmers can lead to imbalance and, thus, reduced **Glenohumeral** stability. Other muscles involved are the **Serratus anterior** which helps to position and stabilize the scapula and the **Subscapularis** which acts as an internal rotator throughout the stroke. The repeated contraction of these muscles throughout the stroke makes them prone to fatigue.

Phases of the freestyle stroke, shoulder position, and muscle activation.

Stroke Phase	Shoulder Position	Muscle Activity
Hand entry	Abduction, flexion, internal rotation	Upper trapezius, rhomboids, supraspinatus, anterior and middle deltoids, serratus anterior
Early pull-through phase (maximum forward extension to 90° flexion)	Adduction, extension, neutral rotation	Pectoralis major, teres minor, serratus anterior
Late pull-through phase (90° flexion to hand exit)	Full adduction, extension, internal rotation	Latissimus dorsi, subscapularis, serratus anterior
Recovery phase	Extension, abduction, internal rotation	Anterior middle posterior deltoid, supraspinatus, subscapularis, rhomboids

Image 4: Table of the Muscles used in the different phases of Freestyle

“Prevention and Treatment of Swimmer’s Shoulder.” *North American Journal of Sports Physical Therapy : NAJSPT*, vol. 1, no. 4, 1 Nov. 2006, www.ncbi.nlm.nih.gov/pmc/articles/PMC2953356/#:~:text=Stroke%20power%20is%20achieved%20through. Accessed 29 Oct. 2021

Anatomy and Epidemiology of Knee Injuries

Structure and Function of the knee

The knee is the joint at which the upper and lower limbs meet. Like the shoulder is a ball-and-socket joint, the knee moves like a hinge. Due to its complex structure, the knee allows a variety of movements such as sitting, running, squatting or jumping. A healthily functioning knee has a

range of motion of 0 degrees (completely straight) to 150 degrees (calf touching the back of the thighs). A bent knee could also be turned inwards by 10 degrees and outwards by 30 degrees. These movements are made possible by the bones, cartilage, muscles, tendons and ligaments involved in the knee joint.

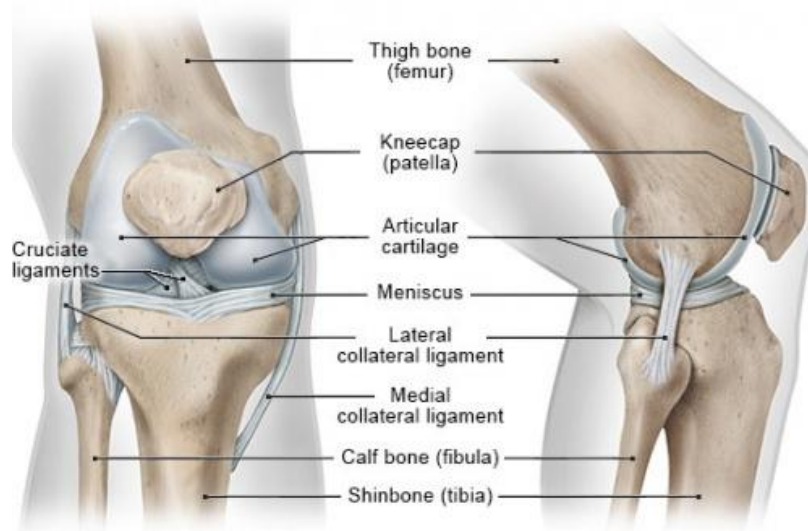


Image 5: The Anatomy of the Knee

How Does the Knee Work?" *Www.ncbi.nlm.nih.gov*, Institute for Quality and Efficiency in Health Care (IQWiG), 13 Aug. 2020, www.ncbi.nlm.nih.gov/books/NBK561512/#:~:text=The%20knee%20is%20the%20joint.

The bones of the knee

Femur: the upper leg bone, commonly known as the thigh bone

Tibia: the bone at the front of the lower leg, commonly known as the shin bone

Patella: the thick, triangular bone that sits over the other bones at the front of the knee, commonly known as the kneecap

Cartilaginous compartments of the Knee

The ends of these articulating surfaces are covered with a layer of cartilage.

Cartilage is a slick, elastic material that absorbs shock and allows the bones to glide easily against one another as they move. It provides a well-lubricated surface that allows smooth, low-friction movement between the bones.

Medial compartment: the joint between the femur and tibia on the inner side of the knee

Medial Meniscus: a crescent-shaped, cartilaginous band found between the medial tibia and medial femur. The primary function is to decrease the amount of stress on the knee joint.¹²

Lateral compartment: the joint between the femur and tibia on the outer side of the knee

Lateral Meniscus: a fibrocartilaginous band that spans the lateral side of the interior of the knee joint.

Patellofemoral compartment: the joint between the patella and its groove on the femur

The bones are held together by a joint capsule, consisting of two distinct layers—an outer layer of dense connective tissue and an inner membrane, called the **synovium**.

Synovial Fluid: present in the articular capsule, it supplies the cartilage tissue with nutrients and acts as a lubricant.

In order for the fluid to enter the cartilage and the waste substances to be transported out, the knee needs to move and

bear weight. When pressure is put on the knee, these waste products are squeezed out of the knee. With a reduction in the pressure applied, nutrients are absorbed from the fluid.

Stability-providing Ligaments

Condyles are two rounded joint surfaces present at the lower end of the femur, with cruciate ligaments run through. The femur's condyles are located opposite two flat, slightly pan-shaped joint surfaces on the tibia. There are two bumps between these two structures, to which the cruciate ligaments attach.

Two collateral (side) ligaments and two cruciate ligaments provide the knee joint with support and protect it from being twisted:

Medial collateral ligament: It connects the inner sides of the femur and tibia, attached to the joint capsule. It stabilizes the inner part of the knee.

Lateral collateral ligament: Connected to the outer sides of the femur and tibia, it's not attached to the joint capsule. It stabilizes the outer part of the knee

Anterior cruciate ligament: It runs from the back of the outer condyle to the front of the tibia. It prevents excessive forward movement of the tibia.

Posterior cruciate ligament: It runs from the front of the inner condyle to the back of the tibia. It prevents excessive backward shifting of the knee

Basic Knee Movements

The medial and lateral collateral ligaments stabilize the knee when the leg is stretched. It prevents the knee from being turned or rotated in this position. These two ligaments limit the excessive valgus and varus movements of the knee.

When the knee is bent, the medial and lateral collateral ligaments relax, and the cruciate ligaments help to support it. When the knee is turned inwards, the cruciate ligaments reach their maximum length and prevent further motion, stabilizing the joint in the direction it's turned in.

¹²“How Does the Knee Work?” *Www.ncbi.nlm.nih.gov*, Institute for Quality and Efficiency in Health Care (IQWiG), 13 Aug. 2020, www.ncbi.nlm.nih.gov/books/NBK561512/#:~:text=The%20knee%20is%20the%20joint.

Muscles and tendons that allow the knee to move

The knee can be bent, stretched and turned with the help of many muscles and tendons, which connect the muscles to the bones. The two main groups of muscles are:

Quadriceps femoris: located on the front side of the thigh, it's commonly known as the quadriceps. It helps to extend the knee.

Hamstrings: located on the back of the thigh, together with other muscles it makes it possible to bend the knee. It is commonly known as the hamstring muscles. The hamstring muscle group comprises the **Semitendinosus**, **Semimembranosus**, and **Biceps femoris** muscles.

Many other smaller muscles are responsible for turning the knee – such as the **Sartorius muscle** and the **Popliteus muscle**.

Epidemiology of Injuries of the Knees:

The knee is the second-most-reported source of pain in competitive swimmers.¹³ However, a greater incidence of knee pain is observed in Breaststrokers. A survey of 36 competitive breaststroke swimmers found that 86% had at least 1 episode of breaststroke-related knee pain.¹⁴

Biomechanical factors affecting knee injuries

As with most injuries, overuse is a predominant factor that causes knee pain and injuries. Being in the water, the repetitive hydrodynamic forces result in stresses that increase the risk of soft tissue injuries. Pain predominantly affects the medial compartment of the knee, although anterior knee pain is also common.

Breaststroke

Breaststroke swimmers have a fivefold higher risk of knee pain, although most occur in the medial compartment, whereas freestyle has a reduced relative risk for knee pain.¹⁵

Due to the kick style in breaststroke, there is increased tension across the medial compartment and increased compression of the lateral compartment. There is also an increased strain of the medial collateral ligament due to the load on the ligament during the whip kick. This can present with a tenderness of the femoral or tibial origin of the MCL. Furthermore, strain injuries of the hip flexors and adductors are also common.

Freestyle, Backstroke & Butterfly

All these three strokes have similar movement patterns of the knee as they involve the flutter kick. The flutter kick

requires repetitive quadriceps contraction, which could lead to patellofemoral overload. This increased patellofemoral contact stress results in anterior knee pain during the push-off from the wall or the diving position. This is due to the forceful quadriceps contraction with the knee in a high degree of flexion during the push-off or the partial squat position during the start.

Extrinsic and Intrinsic Factors

As mentioned before, overuse in breaststroke swimmers contributes to knee pain and injuries. Knee pain in breaststroke swimmers correlates with the number of years of training, the volume of training, the calibre of the athlete, and increasing age.¹⁶ A survey of NCAA Division III college swimmers showed that females had significantly more knee injuries, as well as back/neck, shoulder, hip, and foot problems.¹⁷

Intrinsic factors can contribute to the biomechanical stresses on the knee and the progression of patellofemoral pain. Quadriceps femoris abnormalities may make an individual more susceptible to **patellar maltracking**, which is an imbalance in the dynamic relationship between the patella and kneecap. This could be due to inadequate strength, endurance and flexibility and could potentially lead to patellofemoral pain.

Common Knee Injuries

- 1) MCL strains
- 2) Meniscus injuries
- 3) Patellofemoral pain syndrome (PFPS)
- 4) ACL injuries
- 5) Patella tendinitis
- 6) Adductor strains (groin injuries)

Stroke Biomechanics¹⁸

In order to have a maximum distance per stroke, there are ideal biomechanics involved. This ideal way of swimming the stroke differs for each swimmer based on their body type. For example, the distance covered per stroke for a swimmer with long arms would be more than that covered by a swimmer with shorter arms. Despite these slight differences, there are ideal stroke mechanics that reduce the probability of the onset of injuries.

It's imperative to see how one has deviated from the ideal stroke mechanisms and the extent to which the deviation has occurred. One must first identify the gross mistakes and aim to fix them before fine-tuning the details of the stroke. A few examples of gross mistakes are poor ankle and knee coordination, instability of the shoulders, or insufficient activation of the core. A few examples of minor details are insufficient force production from a particular muscle or an incorrect angle of kicking.

¹³“Epidemiology of Injuries and Prevention Strategies in Competitive Swimmers.” *Sports Health: A Multidisciplinary Approach*, vol. 4, no. 3, 6 Apr. 2012, pp. 246–251, www.ncbi.nlm.nih.gov/pmc/articles/PMC3435931/, 10.1177/1941738112442132.

¹⁴Rupp, S., et al. “Shoulder Problems in High Level Swimmers-Impingement, Anterior Instability, Muscular Imbalance?” *International Journal of Sports Medicine*, vol. 16, no. 08, Nov. 1995, pp. 557–562, 10.1055/s-2007-973054.

¹⁵Knobloch, K., et al. “[200-400 M Breaststroke Event Dominate among Knee Overuse Injuries in Elite Swimming Athletes].” *Sportverletzung Sportschaden: Organ Der Gesellschaft Für Orthopädisch-Traumatologische Sportmedizin*, vol. 22, no. 4, 1 Dec. 2008, pp. 213–219, pubmed.ncbi.nlm.nih.gov/19085772/, 10.1055/s-2008-1027987.

¹⁶Rupp, S., et al. “Shoulder Problems in High Level Swimmers-Impingement, Anterior Instability, Muscular Imbalance?” *International Journal of Sports Medicine*, vol. 16, no. 08, Nov. 1995, pp. 557–562, 10.1055/s-2007-973054.

¹⁷Sallis, R. E., et al. “Comparing Sports Injuries in Men and Women.” *International Journal of Sports Medicine*, vol. 22, no. 6, Aug. 2001, pp. 420–423, 10.1055/s-2001-16246.

¹⁸McLeod, Ian. *Swimming Anatomy*. Champaign, IL, Human Kinetics, 2010, pp. 8–12.

Attached below is the anatomy of the leg muscles to aid in visualization for the next few subsections

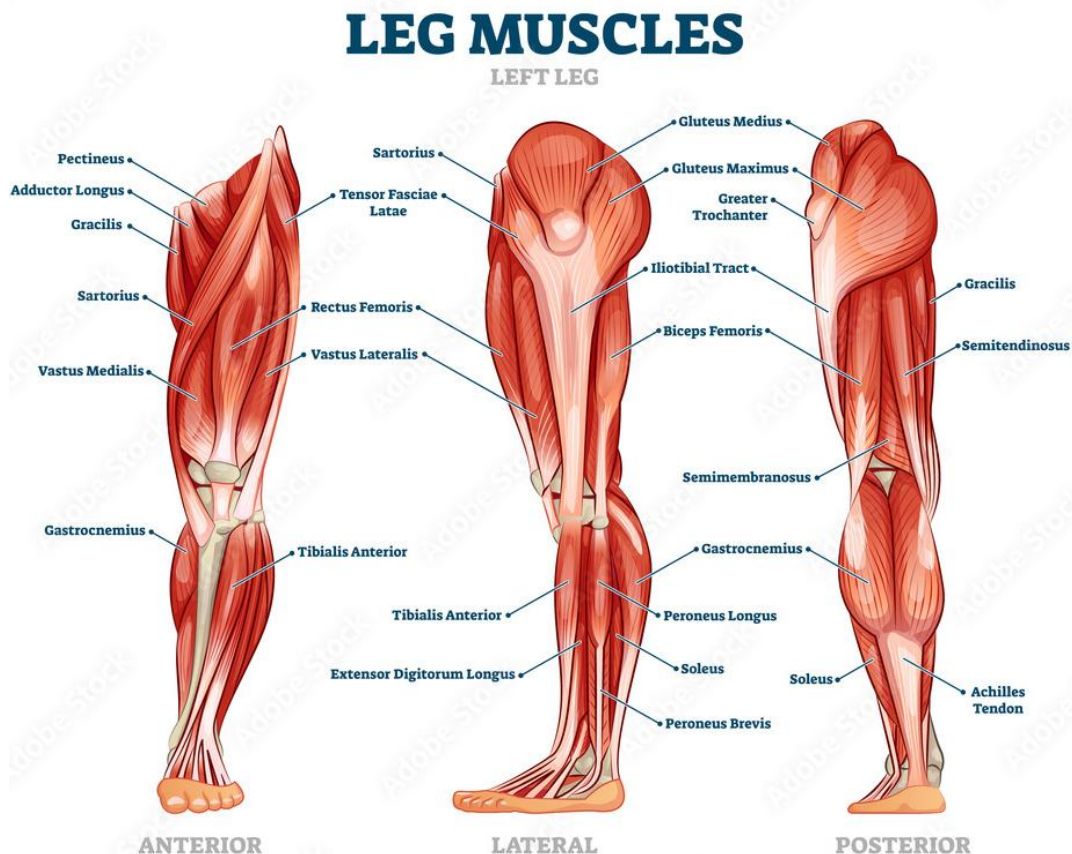


Image 6: A labelled diagram of the leg muscles with anterior, lateral and posterior angles

Freestyle

The two primary phases in this stroke are propulsion and recovery. The propulsion phase can further be broken down into the catch, pull, push and recovery. As the hand enters the water, the wrist and elbow follow. The arm is extended to the starting position of the propulsive phase. The shoulder blade rotates upwards to reach an elongated position in the water, initiating the first part of the propulsive phase, also known as the catch. During this propulsive phase, the wrist flexors act to hold the wrist in a position of slight flexion. Elbow flexors, **Biceps brachii** and **Brachialis**, at the elbow begin to contract during this catch phase, gradually moving from full extension to approximately 30 degrees of flexion.

The initial movements are generated by the clavicular portion of the **Pectoralis major** followed by the **Latissimus dorsi**. These two muscles work together to generate a majority of the force during the pull.

During the final part of the propulsive phase, the **Triceps brachii** extends the elbow, bringing the hand backwards and upward towards the surface of the water. This is also known as the push.

In the recovery phase, the **Deltoid** and **Rotator cuff** (supraspinatus, infraspinatus, teres minor, and subscapularis) are primarily activated, functioning to bring the arm and hand out of the water, near the hips and return them to an overhead position for re-entry into the water.

The arm movements in this stroke are reciprocal in nature, which means that while one arm is in the propulsion phase, the other is in recovery.

Apart from the muscles mentioned above, other muscle groups serve as stabilizers during both these phases. For example, the **shoulder blade** stabilizers (pectoralis minor, rhomboid, levator scapula, middle and lower trapezius, and the serratus anterior). This has the aim of anchoring or stabilizing the shoulder blade. Since the propulsive forces generated by the arm rely on the scapula's firm base of support, efficient functioning of this muscle group is imperative. This muscle group also works with the muscles involved during the recovery phase. The core stabilizers, which are the **Transversus abdominis, Rectus abdominis, internal oblique, external oblique, and Erector spinae** are integral to efficient stroke mechanics as they serve as a link between the movements of the upper and lower extremities. Without this link, there would be poor coordination of the body roll that is central during freestyle.

Kicking movements can also be divided into the propulsive and recovery phase, commonly known as the downbeat and the upbeat. This downbeat begins with the activation of the **Iliopsoas** and **Rectus femoris** muscles. The latter initiated the hip flexion, followed by the extension of the knee. The **quadriceps** (Vastus lateralis, Vastus intermedius, and

Vastus medialis) assist the rectus femoris for a more forceful extension of the knee.

The recovery phase also begins at the hips with the contraction of the **gluteal muscles** (Gluteus maximus and medius) and is immediately followed by the contraction of the **hamstrings** (Biceps femoris, Semitendinosus, and Semimembranosus). Hip extensions are their secondary functions. Throughout the entire kicking motion, the foot is maintained in a plantarflexed position secondary to activation of the gastrocnemius and soleus (calf muscles) and pressure exerted by the water during the downbeat portion of the kick. The calf muscles create the force to keep the foot in a plantarflexed position

Butterfly

While the movements of freestyle and butterfly are very similar, the primary difference between the two is that in butterfly both arms move in unison. Due to the same underwater pull pattern, butterfly follows the same muscle recruitment pattern as freestyle.

Just like freestyle, in butterfly the swimmer's arms are in an elongated position to initiate the propulsive underwater force. The muscles involved are the **Pectoralis major** and **Latissimus dorsi**, which function as the primary movers, and the **wrist flexors**, which act to maintain the wrist in a neutral to a slightly flexed position. The **Biceps brachii** and **Brachialis** are active as the elbow moves from being fully extended at the initiation of the catch to approximately 40 degrees of flexion during the midpart of the pull. Unlike in freestyle, a forceful extension of the elbow is emphasized during the final portion of the pull, resulting in greater demands being placed on the triceps brachii. As in freestyle, the **Rotator cuff** and **Deltoid** are responsible for moving the arm during the recovery phase, but the mechanics are somewhat different.

Butterfly lacks the body roll that aids the recovery process during freestyle. Instead, an undulating movement of the torso occurs, which brings the entire upper torso out of the water to aid in the recovery process. Again, the **shoulder blade stabilizing** muscles are extremely important, as they function to provide a firm anchor point for the propulsive forces generated by the arms and help reposition the arms during the recovery phase of the stroke. Although butterfly lacks the body roll present in freestyle, the core stabilizers are still important in linking the movements of the upper and lower extremities and have an important role in creating the undulating motion that allows the swimmer to get the upper torso and arms out of the water during the recovery process.

The undulating movement is initiated with the contraction of the **Paraspinal** muscles that run in multiple groups from the lower portion of the back to the base of the skull. This contraction results in an arching of the back, at which time the arms are moving through the recovery process. Contraction of the **abdominal** muscles quickly follows, which prepares the upper body to follow the entry of the hands into the water to initiate the propulsive phase of the stroke.

The kicking movements in the butterfly kick are identical to those used during freestyle except they are used together. The downbeat begins with the contraction of the **Iliopsoas** and **Rectus femoris**, acting as hip flexors.

The firing of the **quadriceps muscle group** aids the rectus femoris in knee extension. The **gluteal muscle group** drives the recovery phase of the kick. Concomitant contraction of the **hamstring muscles** also works to extend the hip.

The dolphin kick that is used at the start of the race and of each turn wall recruits a larger group of muscles than the smaller, more isolated kick tied into the arm movements. Apart from the movements generated at the hips and knee, the dolphin kicks tie in the undulating movements of the torso through activation of the core stabilizers and the paraspinal musculature. The foot is maintained in a plantarflexed position through a combination of the resistance from the water and activation of the gastrocnemius and soleus, acting as plantar flexors.

Backstroke

Backstroke can also be divided into the propulsive phase, a catch, finishing and recovery phase. The little finger enters the water first by shoulder rotation. The extension of the elbow allows the swimmer to be in an elongated position to begin the underwater propulsion phase of the stroke.

A difference between backstroke and freestyle or butterfly is that the initial catch component in backstroke is dominated by **Latissimus dorsi** and the **Pectoralis major** makes a smaller contribution. Despite these differences, both muscles are still the primary muscles that are active to some extent through the propulsive phase. The wrist is maintained in a neutral to a slightly extended position, even though the wrist flexors are an integral part of the propulsion phase. The elbow transitions into approximately 45 degrees of flexion at the start of the catch through a combination of pressure forces from the water and activation of the **Biceps brachii** and **Brachialis**. At the end of the catchphrase, the elbow could be flexed to a maximum of 90 degrees before transitioning to the finish. At this stage, there is a greater emphasis on forceful extension of the elbow, placing high demand on the **Triceps brachii**.

Since backstroke and freestyle both have a similar reciprocal arm movement along with body roll, the role of the stabilizing musculature during both strokes is very similar. The kick in backstroke is a combination of freestyle and butterfly movements. Backstroke uses reciprocal kicking movements, however the position of the swimmer in the water causes the upbeat of the kick to generate the most force. Backstroke also uses the dolphin kick at the start of a race and of each wall. The muscle recruitment patterns are the same in each case, however, the only change is in the direction because of the swimmer's body position.

Breaststroke

The movements in breaststroke can also be divided into the propulsive and recovery phase. The shoulders and arms are in an elongated position, indicating the beginning of the propulsive phase. The first half of the underwater pull is similar to that used in freestyle and butterfly, where the

clavicular portion of the **Pectoralis major** starts the movement followed by the **Latissimus dorsi**.

In the second half of the pull, the forceful contractions of these two muscles pull the arms and hands into the midline of the body to complete the pull. Aided by the contraction of the **Paraspinal muscles**, the forces generated during the final phase are for the forward propulsion of the swimmer in the water and the upward propulsion of the swimmer's torso. This brings the swimmer's head and shoulders out of the water. The transition to the recovery phase is marked by the flexion and rotation at the elbow that brings the hands to the midline of the body. The arms must be returned from their position under the chest back to the starting position. This is carried out by the recruitment of the **Pectoralis major**, **Anterior deltoid**, and the long head of the **Biceps brachii**, which all function to flex the shoulder joint. Simultaneously, the **Triceps brachii** extends the elbow. The arms are in an extended and elongated position, indicating a completion of the recovery phase.

Just as with the other strokes, the shoulder blade stabilizing musculature is crucial to create a firm base of support for the movements and forces generated by the arms. Even though breaststroke, like butterfly, lacks a body role, the core stabilizing musculature is important in ensuring an efficient link between the movement patterns of the upper and lower extremities.

As with the arm movement, the kicking movement is also unilateral and can be divided into a propulsive and recovery phase. The propulsive phase consists of outswEEP and inswEEP components. It begins with the feet hip-width apart, with the knees and hips in a flexed position. The outswEEP is initiated with the outward rotation of the feet which is made possible by a combination of hip, knee and ankle movements. This outer sweeping motion is continued by hip and knee extensions.

The hip is extended by the **Gluteal musculature** and the **hamstrings** while the **Rectus femoris** and **quadriceps** straighten the knees. At the transition to the inswEEP, the knees and hips are only partially extended, hence the muscle groups mentioned above continue their action until complete hip and knee extension is achieved.

During the initial stages of the inswEEP, the legs are in an abducted position. The motion requires the hips to be adducted while simultaneously being extended to produce a whip-like motion. The contraction of the **adductor muscles** that run along the upper portion of the inner thigh brings the legs back together. The calf muscles are activated to bring the foot and ankle into a pointed position to minimize drag during the final position of the inswEEP. The recovery phase is achieved by the flex of the hip and the knee, which is achieved by the recruitment of the calf muscles, the **Rectus femoris** and **Iliopsoas**, and the **hamstring muscles** respectively.

Analysis and Interpretation of Strokes

Importance of stroke analysis

Stroke analysis is important in competitive swimming to:

- 1) Reduce the chances of injuries
- 2) Improve the efficiency of the stroke

Methods for musculoskeletal and stroke assessment

It's natural for every swimmer to have at least one error in the mechanics of a stroke, hence there are multiple ways to identify and measure these errors. Assessment of muscular strength and power generation of all the different muscles involved is conducted to identify these errors.

Video analysis

This is perhaps one of the most beneficial methods of stroke analysis. Analyzing a swimmer's stroke by only over-water observations can be deceptive. By viewing the stroke underwater with the help of underwater cameras, the coach and the swimmer can assess the movements that occur underwater, and correct any discrepancies or errors.

1, 3 RM Testing

The one-repetition maximum (1RM) test is often considered the 'gold standard' for assessing the strength capacity of individuals. It is simply defined as the maximal weight an individual can lift for only one repetition with the correct technique. A 3RM test is used to find the maximum weight a person can lift 3 times. A 3 RM is estimated to be around 93% of the weight of the 1RM. 1RM tests have higher chances of injury as compared to 3RM tests, hence the latter is usually conducted.

Isokinetic Testing

Isokinetic testing is a strength test for the muscles around the knee using specific equipment. They have been shown to produce relatively reliable data by testing simple, uniaxial joints such as the knee.¹⁹ It could be used to compare the strength of the two legs. This test is useful for an individual with a knee injury or is recovering from surgery or suffering from a long-term problem with the knee. Isokinetic muscle testing is performed with a constant speed of angular motion but variable resistance.

Electromyograph²⁰

EMG is a technique used to assess the health of muscles and the nerves (motor neurons) that control them.²¹ Motor neurons transmit electrical signals to contract muscles. An EMG uses electrodes to translate these signals into graphs, sounds or numerical values that are then analyzed. Since swimming is highly dependent on the coordination between the different muscles in both the upper and lower extremities, such a scan can be beneficial as it can reveal any

¹⁹Almekinders, Louis C., and Janine Oman. "Isokinetic Muscle Testing: Is It Clinically Useful?" *Journal of the American Academy of Orthopaedic Surgeons*, vol. 2, no. 4, July 1994, pp. 221–225, 10.5435/00124635-199407000-00005. Accessed 21 May 2020.

²⁰Pilkar, Rakesh, et al. "Use of Surface EMG in Clinical Rehabilitation of Individuals with SCI: Barriers and Future Considerations." *Frontiers in Neurology*, vol. 11, 18 Dec. 2020, 10.3389/fneur.2020.578559. Accessed 9 July 2021.

²¹"Electromyography (EMG)-Mayo Clinic." *www.mayoclinic.org*, 21 May 2019, [www.mayoclinic.org/tests-procedures/emg/about/pac-20393913#:~:text=Electromyography%20\(EMG\)%20is%20a%20diagnostic](https://www.mayoclinic.org/tests-procedures/emg/about/pac-20393913#:~:text=Electromyography%20(EMG)%20is%20a%20diagnostic). Accessed 29 Oct. 2021.

nerve or muscle dysfunction, or errors with nerve-to-muscle signal transmission.

After identifying any errors in the stroke mechanics or muscles involved in a particular phase of the stroke, an exercise or rehabilitation regime is created to attempt to solve the problem. For weakness or lack of stability of a muscle, four improvements are made: flexibility, stability, mobility, and strength & conditioning. Exercises are tailored to improve flexibility, stability, mobility and strength-in that order. The swimmer or athlete is then re-assessed and the same process is repeated.

Factors affecting the rate of injuries

Swimmers face several unique challenges that athletes in most land-based sports do not encounter. The first challenge is the coordinated effort of the entire musculoskeletal system for all four strokes. Movements of both the upper and lower extremities are required to ensure each body part moves correctly through the water, maximizing the efficiency of the swimmer.²²

To understand the coordinated effort required in the sport, it’s important to the concept of the Kinetic Chain²³ which describes how the human body can be considered in terms of a series of interrelated links or segments.

One could imagine the body as a long chain, with each body segment as a link. Since all the segments are linked together, a movement in one segment has an effect on all the others. This kinetic chain enables the power generated by the upper body to be transferred through the torso to the lower body. However, if one such linkage in the chain is weak, there is a potential for loss of power transfer. This could lead to uncoordinated body movements, a reduction in the efficiency of movement, and an increase in the risk of injury.

Defined by the International Olympic Committee Injury and Illness Epidemiology Consensus as a “tissue damage or other derangements of normal physical function due to participation in sports, resulting from the rapid or repetitive transfer of kinetic energy”²⁴, there are multiple factors involved in the risk of injury occurrence and the interaction between these factors may increase the risk of injuries.

Table 1: Factors that affect the rate of injuries

Training-related factors	Training volume, load, intensity
	Type of training
	Training and competition schedule
	Rest

²²Mcleod, Ian. *Swimming Anatomy*. Champaign, IL, Human Kinetics, 2010, pp. 5–12

²³Ellenbecker, Todd S., and Ryoki Aoki. “Step by Step Guide to Understanding the Kinetic Chain Concept in the Overhead Athlete.” *Current Reviews in Musculoskeletal Medicine*, vol. 13, no. 2, 14 Mar. 2020, pp. 155–163, 10.1007/s12178-020-09615-1. Accessed 23 Oct. 2020.

²⁴Bahr, Roald, et al. “International Olympic Committee Consensus Statement: Methods for Recording and Reporting of Epidemiological Data on Injury and Illness in Sports 2020 (Including the STROBE Extension for Sports Injury and Illness Surveillance (STROBE-SIIS)).” *Orthopaedic Journal of Sports Medicine*, vol. 8, no. 2, 1 Feb. 2020, p. 232596712090290, 10.1177/2325967120902908. Accessed 25 Feb. 2021.

	Poor core stability and strength
Motor control factors	Posture
	Movement patterns
	Muscle tone
	Technique
	Sports specific biomechanics
	Poor flexibility, stability or mobility
	Decreased muscle strength
Health-related factors	Diet
	Medication
	General health
	Fatigue
	Sleep patterns
Non-modifiable factors	Gender
	Age
	Maturation stage
	Body type
	Genetics
	Previous injuries
Conditioning factors	Strength
	Endurance
	Muscle length
	Joint range of motion

Having understood the factors that affect the onset of injuries, it’s imperative to know the factors that influence the recovery and rehabilitation from an injury.

Factors that affect rehabilitation and recovery

Injury recovery

Depending on the severity of the injury, the activity of the muscle is controlled. Rest and low-to-moderate amounts of movement are suggested in order to reduce the muscle’s strength loss.

If slight passive movements cause pain, then the muscle is completely immobilized to ensure complete and efficient recovery.

Different Treatment Modalities used during Recovery & Rehabilitation

Ice and Heat Fermentations

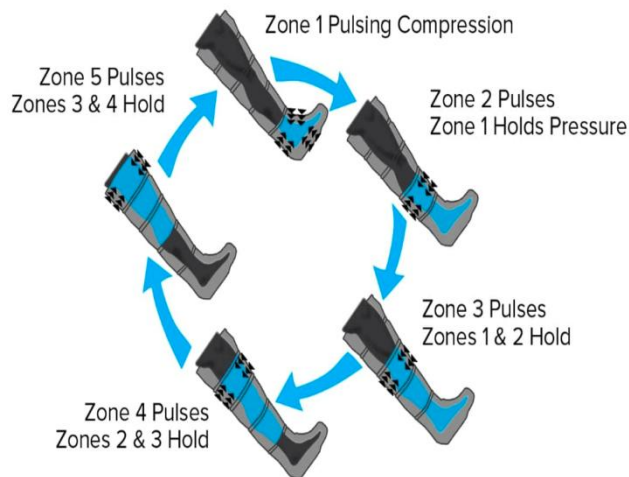
Heat and cold therapy are often recommended to help relieve an aching pain that results from muscle or joint damage. Ice decreases circulation, metabolic activity and inflammation thereby decreasing pain, swelling and muscle spasms. Icing is suggested for acute injuries. Heat fermentation promotes blood flow, helps muscles relax and is usually suggested for chronic pains.

As a more advanced treatment, ice and heat are suggested to be applied in an alternative model. Icing for 20 minutes causes constriction or narrowing of blood vessels. Heating for 15 minutes causes the vessels to dilate. This serves as a pumping mechanism to the inflammation, pushing it away from the injured area.²⁵

²⁵“When to Treat to Pain with Ice vs Heat?” *OrthoCarolina*, www.orthocarolina.com/media/ice-vs-heat-what-should-i-use-when. Accessed 29 Oct. 2021.

Compression Therapy

Compression is effective in minimizing soreness after exercise and helping athletes recover faster. Reduction in swelling. Compression boots extend from the toes to the top of the femur and have attachments for the hips, lower back and arms. Each boot has five chambers that fill with air working in a distal to proximal sequence. This is meant to assist the function and sequence with which our veins, musculature and lymphatic system works. The goal is to clear the deoxygenated blood and metabolic waste centrally to be filtered and re-oxygenated by the central organs.



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Image 7: The zones of activation of the compression boot

This is meant to create an environment favourable to a quicker recovery, as well as several proposed benefits:

- Improved tissue perfusion
- Increase in total haemoglobin and oxygenated haemoglobin in muscle
- Improved range of motion
- Decrease in pain pressure threshold
- Decreased muscle fatigue
- Promotes relaxation

Care Therapy®

This is a method using bio-stimulation to produce important analgesic, anti-inflammatory and tissue repair effects, hence increasing the rate of recovery of the athlete. In this method, energy is stimulated directly from the inside of the muscle tissue as compared to other treatments in which energy is transferred to the patient from the outside.

Laser Therapy²⁷

Light Amplification by Stimulated Emission of Radiation therapy involves the application of low-intensity laser light to relieve pain due to the damage of soft tissue. It facilitates tissue repair and regeneration while also restoring normal cell function.

²⁶Reinold, Mike. "Compression Therapy for Recovery." *Mike Reinold*, 1 Feb. 2021, mikereinold.com/compression-therapy-for-recovery/. Accessed 29 Oct. 2021.

²⁷Physiotherapy, C. B. "What Is LASER Therapy? What Conditions Are Treated by LASER Therapy? Who Will Benefit from LASER Therapy?" *Cbphysiotherapy*, cbphysiotherapy.in/therapies-offered/laser-therapy. Accessed 29 Oct. 2021.

Therapeutic Ultrasound

Therapeutic ultrasound is a noninvasive procedure that uses low-power ultrasound waves to create vibrations and/or raise the temperature of body tissue in a targeted area, providing pain relief and loosening tight muscles.²⁸

Cryotherapy

Cryotherapy is the use of cold in the treatment of acute and subacute injury as well as to decrease the discomfort after athletic reconditioning.²⁹ Regular cryotherapy treatment has been reported to reduce inflammation and injury swelling, relieve muscle pain (natural analgesia), enhance recovery times and increase overall energy.

Dry Needling

Dry needling is a technique for the treatment of pain and movement impairments. The technique uses a "dry" needle, one without medication or injection, inserted through the skin into areas of the muscle. The needle targets trigger points that develop within stressed muscles. The needle can stimulate them to release so that the muscle can return to normal mobility with less pain.

Cupping

Cupping therapy can be used to help the body heal faster. Suction from cupping draws fluid to the treated area. This suction force expands and breaks open capillaries under the skin, which is treated like an injury by the body. Hence the body sends more blood to that area to stimulate the natural healing process. Cupping can also help stimulate the chemical breakdown of any toxins within the body and reduce inflammation.

Instrument-assisted soft tissue mobilization (IASTM)

This is a skilled myofascial intervention used for soft-tissue treatment. It's a method that involves using instruments usually made of stainless steel and contours that conform to different body anatomical locations, allowing for deeper penetrations. Their ergonomic designs allow the physiotherapist to treat the affected area with appropriate levels of pressure.

Taping

Taping is commonly used as an adjunct or temporary technique. Athletes often make use of taping as a protective mechanism in the presence of an existing injury. Some of the goals of taping are to restrict the movement of injured joints, and soft tissue compression to reduce swelling.

There are three different types of tapes used, with different functions. These are Kinesio, rigid and dynamic. As the names suggest, Kinesio tapes are used to aid muscle movement, relieve pain, reduce swelling and inflammation, and provide support to joints and muscles; rigid tapes are used to restrict movement by providing very firm support;

²⁸"Therapeutic Ultrasound." *Northeast Spine and Sports Medicine*, www.northeastspineandsports.com/treatments/therapeutic-ultrasound/. Accessed 29 Oct. 2021.

²⁹"Cryotherapy Sports Injury & Recovery Treatments, Shrewsbury. Cryozone Health." *Cryozone Health*, www.cryozonehealth.co.uk/benefits/sports/#:~:text=Regular%20cryotherapy%20treatment%20has%20been. Accessed 29 Oct. 2021.

dynamic taping is used to biomechanically provide an external force to assist a weak or overloaded region of the body.

Sports Massages

Sports massage can aid in the rehabilitation process, it can speed healing and reduce discomfort. The techniques used in sports massage can be effective for both acute and chronic injuries. There are two types of sports massages, flush and deep tissue.

Flush massages involve light pressure and rapid motion to increase circulation in the body. It helps the body warm up, hence should be done before or on the competition day. Deep tissue massages are primarily used to treat musculoskeletal tissues. It involves applying sustained pressure using slow, deep strokes to target the inner layers of the muscles and connective tissues.

External factors

Some external factors also affect rehabilitation and recovery. These are nutrition, sleep and medications.

Sleep

Sleep enhances muscle recovery through protein synthesis and human growth hormone release. Without sleep, muscles cannot recover from the stress they were put through during exercises. Lack of sleep could also contribute to the onset of increases as it could lead to joint pain and stiffness.

Nutrition

During post-exercise recovery, optimal nutritional intake is essential to replenish endogenous substrate stores and facilitate the muscle-damage repair and reconditioning. After exhaustive endurance-type exercise, muscle glycogen repletion forms the most critical factor in determining the time needed to recover. Through an online course, I learned the role nutrition plays when the body recovers from the stress of exercise. Further discussions with nutritionists and research papers, led me to one of my understandings: carbohydrates and proteins enhance glycogen resynthesis and remodel skeletal muscle proteins.

Medications

Medications such as non-steroidal anti-inflammatory drugs (NSAIDs), platelet-rich plasmas (PRPs) and localized steroid injections are often used for injury rehabilitation and recovery. NSAID use can improve the recovery from acute muscle injury by reducing strength loss, soreness, and blood creatine kinase level.³⁰

High levels of creatine kinase generally indicate recent muscle damage. PRP has been shown to promote muscle recovery via anabolic growth factors released from activated platelets, and in doing so, potentially reduces pain, and swelling.³¹ Localized steroid injections can quell

inflammation enough to push a tissue into the second stage of healing and promote better growth of new cells.³²

Discussion of my biomechanical assessment at ABTP

As mentioned in the previous sections, biomechanical assessments were conducted on me by ABTP to analyse my musculoskeletal structure to identify unstable or weak regions of my body.

A few of the tests I had to do were: Squat Jumps, Gait analysis, Repeated countermovement jumps, and run analysis. Balance both feet, Stability assessment open eyes versus closed eyes, Postural Assessment, and Gait Analysis. These assessments helped the physiotherapists visualise the weaker areas in my body, and accordingly gave me an exercise regime to improve these areas.

Postural Bench Analysis

Postural bench analysis is conducted to determine the relative tightness of different parts of the posterior chain of muscles. Three levels are assessed-scapular, lumbar and pelvic. They are compared against each other and the left side is compared against the right.

There is always going to be some discrepancy between the right and left sides due to the dominant and non-dominant nature of the human body. Minor differences between the two sides are disregarded unless they are directly affecting the mechanism of injury.

Since athletes need to be highly flexible, the tightness of the muscles, either due to hypertonicity of the muscles or the structural shortening of the muscles can contribute towards injury as it has a profound effect on the mechanics of the joint movement.

Analysing the posterior chain and identifying the problem areas can be highly useful in understanding injury mechanics and as a prevention tool for probable future injuries.

³⁰Morelli, Kimberly M., et al. "Effect of NSAIDs on Recovery from Acute Skeletal Muscle Injury: A Systematic Review and Meta-Analysis." *The American Journal of Sports Medicine*, vol. 46, no. 1, 29 Mar. 2017, pp. 224–233, 10.1177/0363546517697957. Accessed 14 Apr. 2020.

³¹Setayesh, Kian, et al. "Treatment of Muscle Injuries with Platelet-Rich Plasma: A Review of the Literature." *Current Reviews in*

Musculoskeletal Medicine, vol. 11, no. 4, 20 Oct. 2019, pp. 635–642, 10.1007/s12178-018-9526-8. Accessed 25 Jan. 2021.

³²DPT, Garnet Loveday PT. "Benefits and Drawbacks of Cortisone Injections." *Buffalo Rehab Group*, 5 June 2018, buffalorehab.com/blog/benefits-and-drawback-of-cortisone-injections/. Accessed 29 Oct. 2021.

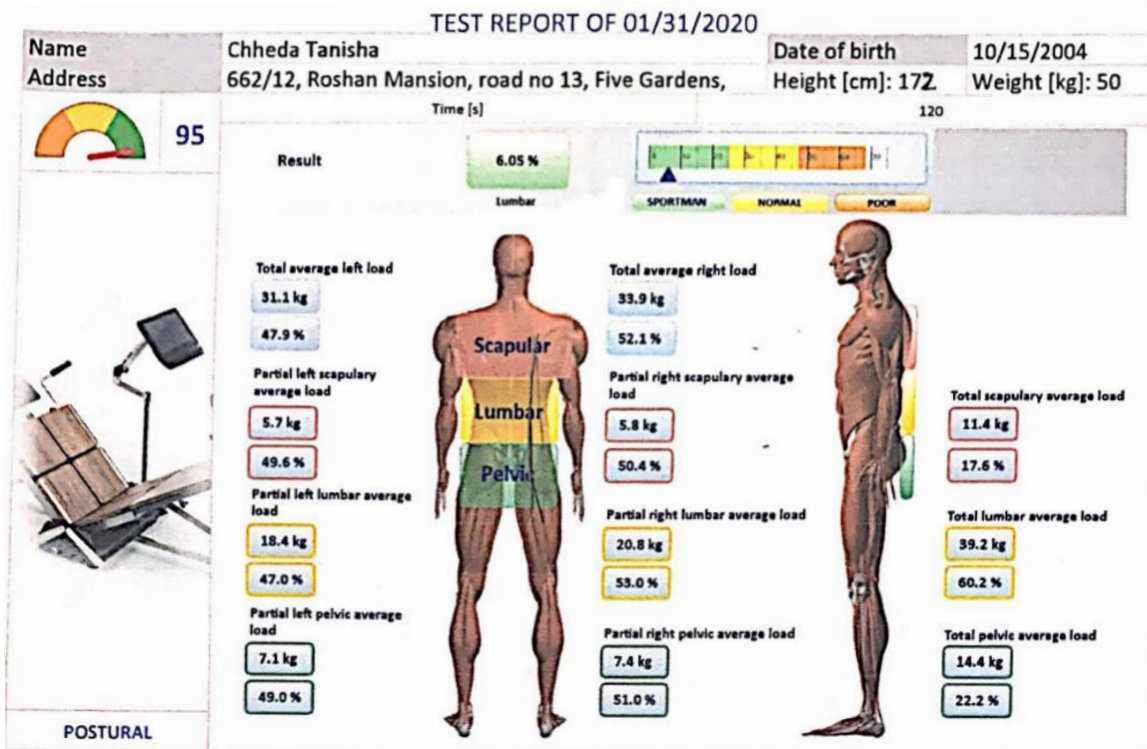


Image 8: Results of the Postural Bench Analysis

Squat Jumps

Muscles need to be activated sequentially to achieve the maximum distance at the start, off the starting blocks. For this, the muscles need to generate explosive momentum from a static position. To assess my efficiency to generate power, a movement that mimics the same on land, squat jumps, was performed on a force plate. This test gave me valuable and useful data which I could use to evaluate my

jump efficiency. Faults in my mechanics and muscles whose underperformance affected my dive were identified through this test, along with video analysis.

Further discussions with my mentor led me to understand that more refined data could have been produced if this test was coupled with EMG sensors. However, we were unable to do this as these sensors were unavailable then.

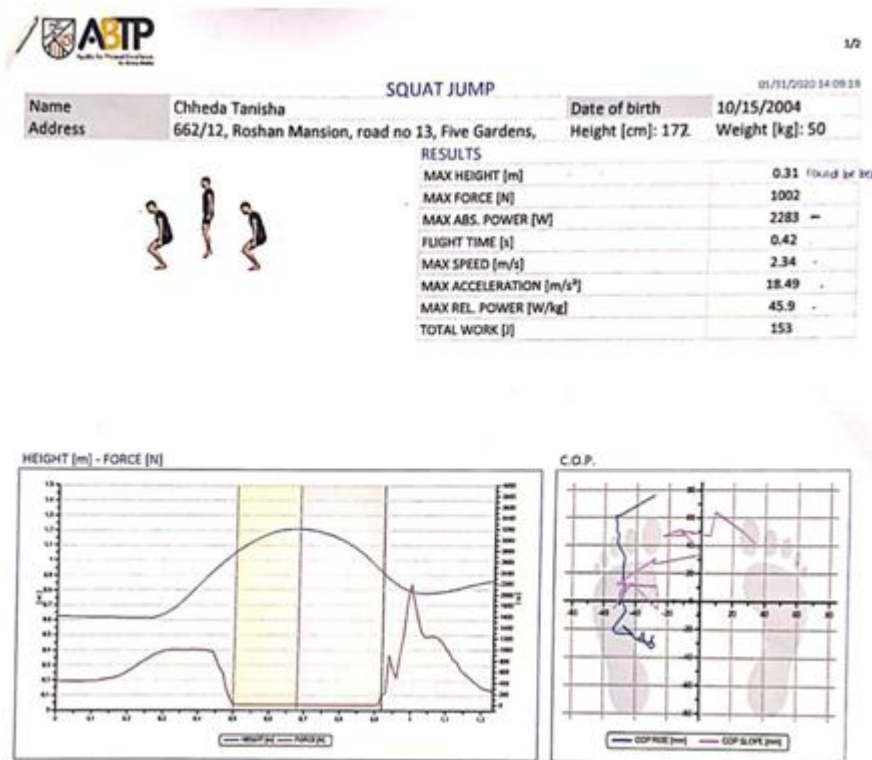


Image 9: Results of the Squat Jump Test

Repeated Countermovement Jumps

Just the way squat jumps mimic the start of the blocks, repeated countermovement jumps can do the same with flip-turns, or tumble-turns off the pool wall. These repeated countermovement jumps are performed when the body is

already in motion, just as the flip-turns in the pool. This gives us the relevant data to assess and compare the two types of jump techniques that are vital for my race and ideate strategies to improve them.

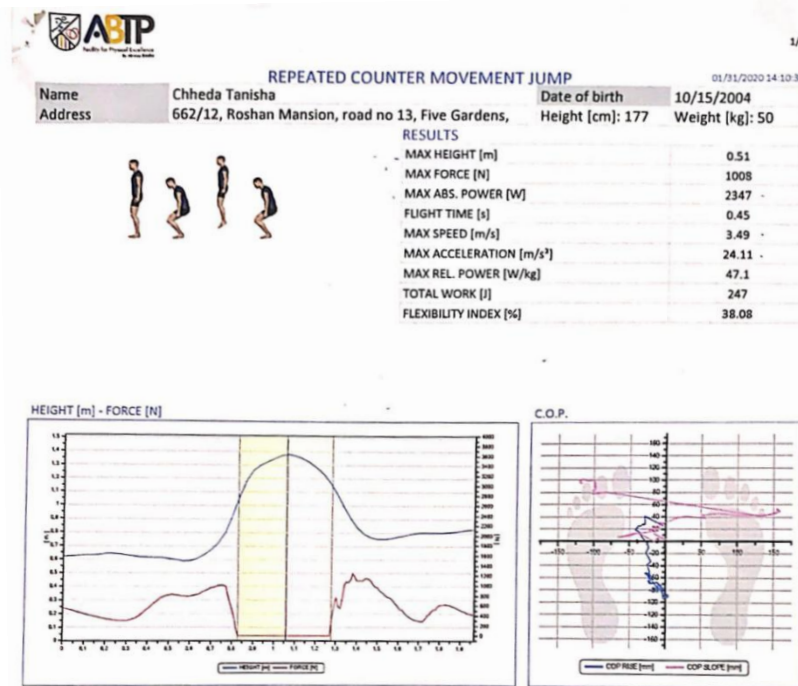


Image 10: Results of the Repeated Countermovement Jump

Balance Tests

Balance can be directly linked to the amount of control one has the potential to exert on his/her body through efficient coordination between various sensory and motor pathways. My balance was evaluated in static and dynamic situations which are discussed in detail below.

Static Balance Test (open eyes versus closed eyes)

There are three major sensory inputs that the brain uses to collect data on the positioning of the body:

- 1) Vision
- 2) Semicircular canals in the internal ear
- 3) Proprioception/ Kinesthetic Sense

While discussing this test, the focus will lie on two out of several major parameters: the ellipse area (mm²), and the perimeter (mm). The ellipse area is the area in which I was able to maintain my centre of pressure in my base of support for the duration of the test, which is 30 seconds. The

perimeter is the distance my centre of pressure moved through because of my body's sway during the test. Lower values of these parameters indicate higher levels of balance.

During the open eyes test, all three of the sensory inputs were used, and during the closed eyes, my vision was cut-off. This gives us an idea of my dependence on vision to maintain my balance and coordinate with my body. Swimming is a sport in which vision does not play a significant role in the way one orients their body or performs their stroke, hence, the other two sensory inputs play a crucial part to coordinate the body for the most efficient movement pattern. From the data that was gathered, it was evident that I was highly dependent on my vision for my balance as, during my closed eyes test, the values of ellipse area and perimeter were relatively very high. Due to this, a lot of focus was directed towards performing coordination exercises to improve my body awareness.

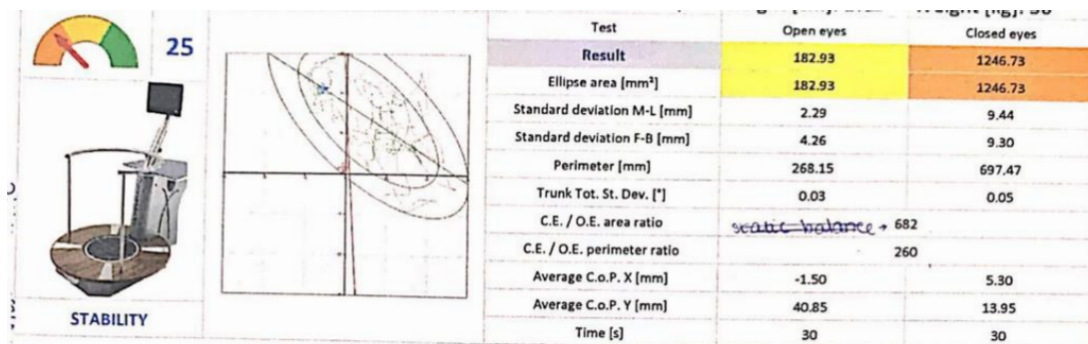


Image 11: Results of the Static Balance Test

Dynamic Balance Test

Dynamic balance test was performed on a dynamic (wobbly) platform. The task during this test was to keep my centre of pressure in the green zone of the concentric circles shown in Image 12 below. This correlated to and evaluated my ability

to make minor changes to my movement patterns to reorient my body while swimming through various phases of my stroke.

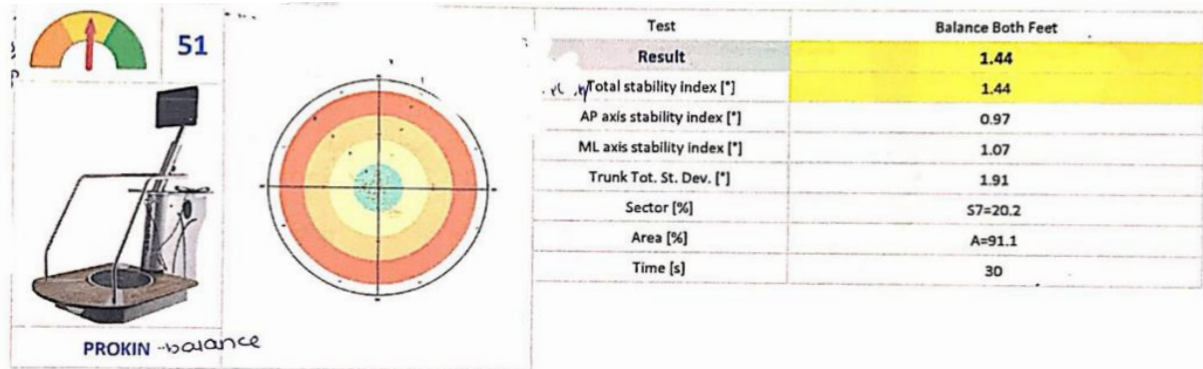


Image 12: Results of the Dynamic Balance Test

Trunk MF Test

This particular test evaluated the available range of motion and control in my hip, pelvis and core complex. As mentioned earlier, the body works as an interlinked chain of muscles and joints (kinetic chain). The pelvis and core complex act as an interconnecting link between the upper and lower extremities. A good range of motion and control

over the hip, pelvis and core complex will lead to better transfer of momentum and will contribute towards increased stroke efficiency. With an Average Tracing Error (ATE %) of 24.03 and 27.55, my performance was average and I was prescribed mobility and coordination exercises to improve this.

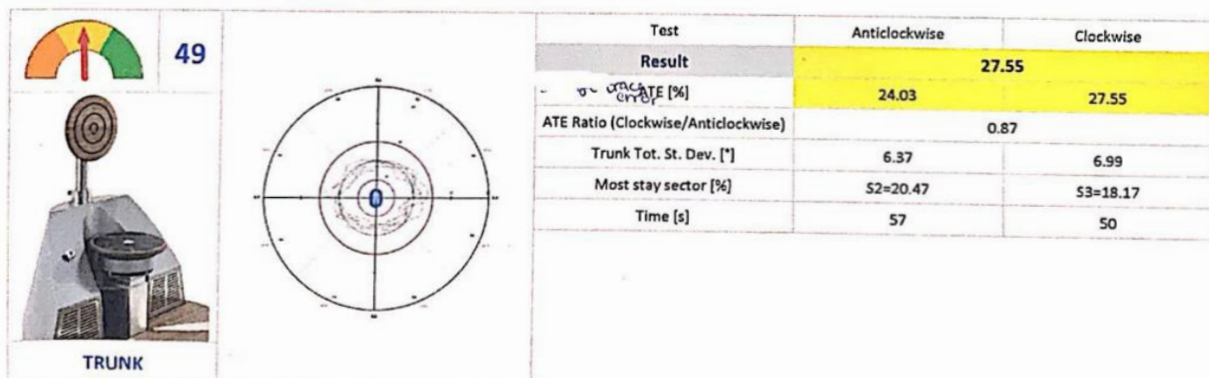


Image 13: Results of the Trunk MF Test

Even though there were multiple other tests carried out, the depth of each of those assessments and the ones already discussed above are beyond my area of expertise and knowledge. I have done my best to learn as much as I can about these assessments and results through discussions with my physiotherapist and the available resources at my disposal. However, I am eager to delve deeper into this field to build an expertise which would enable me to realise my goals.

certain factors are applicable for athletes across all sports. The final aim is to conduct research that is worth publishing in international journals and be used as a stepping-stone through which other medical professionals, coaches, and athletes can reduce the rate of injuries in swimmers and formulate better protocols for rehabilitation in the future.

Extension of the Project

This project had a few limitations from the beginning, as I did not have access to various assessment equipments and experts which would enable me to understand this more deeply and correlate that knowledge with my body movements. However, I intend to continue this project in the future and investigate other factors that may influence an athlete's injury and recovery rate. While this project was a learning opportunity for me and is primarily focused on swimmers, I aspire to do further research to understand how

Acknowledgements

I express my sincere gratitude to my mentor, Mr. Nachiket Kosode for supporting me throughout this research project during my time spent at Bangalore and Mumbai. His expertise and guidance has broadened my knowledge in the field of sports science and biomechanics of the human body.

I extend my gratitude to The Abhinav Bindra Targeting Performance centre in Bangalore where I did my biomechanical assessment. Their technology and methods of treatment has not only supported me in the pool while I was training but also enhanced my desire to write this research project.

This project provided me with an opportunity to gain an understanding of the field of research, and added to my interest and curiosity for the same.

Furthermore, I would like to thank my coach Sandeep Sejwal for educating me about the biomechanics of swimming, my nutritionist Kinita Kadakia Patel for explaining the importance of nutrition to me and all those who have inculcated the love of sports and science within me throughout the years.

My Story

I have been swimming competitively since the age of 5 and swimming has always been an integral part of my life. Just as much as swimming has been a part of my life, so have injuries. Over the years, I've come to realise that while injuries are inevitable in any athlete's life, there are multiple ways to ensure that an athlete isn't kept away from the sport for an extended period.

I came to the Dravid-Padukone Centre of Sports Excellence in 2019 when I was 14 years old to train at Dolphin Aquatics, under the Indian Coach, Mr. Nihar Ameen. After a few days, I witnessed frequent pains in my shoulder and lower back, which led me to the Abhinav Bindra Targeting Performance (ABTP). ABTP is an advanced physiotherapy and rehabilitation centre installed with technological devices from around the world that solely depend on data-driven analysis to deliver accurate and precise results about the musculoskeletal anatomy of an individual.

A biomechanical assessment was conducted on my shoulder, wherein the physiotherapists analysed certain parameters such as posture, diet, the intensity of training, amount of muscles and history of pain to deduce the cause of the pain.

After the nature of the injury was disclosed, I was curious about what caused the injury. The pain stemmed from my rotator cuff, but its root was the lack of strength and stability in the muscles that control the movement of my scapular (shoulder blade). My rotator cuff was compensating for the lack of force production, which led to increased fatigue and change in the biomechanics of my shoulder movement. This resulted in increased wear and tear of the soft tissue surrounding my shoulder.

I was inquisitive to know about the other regions in my body that could be facing similar issues such as lack of stability or overuse of a muscle. My keen interest in this topic facilitated my discussions with my physiotherapists during the treatment sessions. Within a few weeks, I noticed immediate performance enhancement in the pool, but I was curious about the science and biomechanics behind the recovery.

Through interactions with my physiotherapist and reading about this injury online, I was provided with a different perspective of my own body. I realised that there are so many unique processes that occur in the human body that I was completely oblivious to. I wondered if I was the only unaware one, but after speaking with other athletes at the academy, I realised I wasn't.

After returning to Bangalore in 2020, a biomechanical assessment was conducted on my whole body, revealing interesting findings. Factors such as puberty, the intensity of workouts, nutrition and rehabilitation caused the difference in results. These in turn, also impacted my performance.

I began gathering more knowledge about the biomechanics of recovery and rehabilitation by following certain physiotherapists on social media, watching videos on human physiology and movement, reading research papers on the topic and educating myself through online courses. Learning about this helped me visualise what was going on in my body, a skill that was empowered through the knowledge I derived. While I was feeding my curiosity, I found that swimmers are "predisposed to musculoskeletal injuries of the upper limb, knee, and spine"³³

My time spent at the academy made me reflect on the lack of knowledge athletes have about the biomechanics of their body. This led me to culminate all my findings into a research project to *evaluate the factors that affect the rates of muscle injury, rehabilitation & recovery, with a focus on common shoulder & knee injuries found in swimmers*. In this project, I will also refer to my biomechanical assessment to analyse how these factors affected my musculoskeletal structure and performance.

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