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Head and Neck Injury Prevention Strategies in Rugby Union

Conducting Introductory Workshop for Finnish Rugby Association

DEGREE PROGRAMME IN PHYSIOTHERAPY
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ABSTRACT

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The aim of this practical thesis was to increase knowledge and improve the capability of the players and coaches in Finland to apply evidence-based strategies aimed at preventing head and neck injuries in rugby. A live introductory workshop and information package for the usage of Finnish rugby community was produced to reach this goal. Since injuries can be preventable in many cases, the author wanted to uncover the question, how precludable head and neck injuries are in rugby participation. The objective of this written report was to gather the needed data to be able to plan and deliver the product as well as declare the work process and portray the event. In the theoretical framework of this paper the author reviewed the findings from the literature concerning the principles of injury prevention and explored the current literature about the prevalence and multiple predisposing factors for sustaining a head and cervical injury in rugby.

The workshop event was arranged during spring 2024 in Finland´s national team camp. Due to the importance of the topic, it was crucial to address the existing knowledge of the topic. The occasion began with a foundation in theory, followed by practical application with the participants. The focus was acknowledging the issue, identifying risk factors, examining strategies to target the problem, implementing exercises, and provoking individual processes concerning own competencies of the players. Collaborative learning allowed the participants to combine some clinically relevant information with practical field expertise which they depicted to be beneficial. Open conversation and questions were actuated during the session. As a result, a common consensus was drawn upon the idea, that in rugby training, the neck area should receive the same focus of conditioning as other parts of the body and the correct technique is paramount regarding safety. The majority of the participants reported gaining new knowledge about head and neck injuries and acquiring practical insights into potentially beneficial training interventions.

This thesis aspired to promote safer rugby in Finland. To achieve this goal, more research and practical implementation is required to design, conduct, and evaluate the effectiveness of head and neck injury prevention measures.

Keywords: neck, head, prevention, cervical spine, brain injuries, sports injuries, therapeutic exercise, rugby, team sports, Finland rugby

FOREWORD

“An ounce of prevention is worth a pound of cure.”

Benjamin Franklin (1706–1790)

CONTENTS

LIST OF TERMS

ASCI: Acute spinal cord injury
Back (player): In rugby union, positions numbered from 9-15
Erb's point: A specific location of the brachial plexus in the neck
Forward (player): In rugby union, position numbers 1-8
Foul play: Breaking the laws of the game
HAE: Head acceleration event
Head-on tackle: Direction of the tackler comes perpendicularly in front of the ball carrier
HIA: Head injury assessment
High tackle: a form of tackle where the tackler grasps the ball carrier above the line of the shoulders
Hooker: Player number 2. The player who is in the centre position of the front row of the scrum.
iMG: Instrumented Mouthguard that have embedded sensors to measure linear acceleration and angular velocity
IPP: Injury prevention program
Kick-off: The method of starting each half of a match and at the beginning of each period of extra-time with a drop-kick
Lineout: A lineout is a set piece consisting of a line of at least two players from each team waiting to receive a throw from touch
Prop: Player number 1/3. The outer most front row forward players in the scrum
Restart kick: The method of restarting play with a drop-kick after a score.
ROM: Range of motion
Ruck: State of play in rugby where the 1 or more players of both teams contest the possession of the ball
Rucking: Legally using one's feet to try to win or keep possession of the ball in a ruck
Rugby seven´s: 7 vs. 7 player rugby. An Olympic sport
RU: Rugby Union
RWC: Rugby World Cup
Scrum: State of play in rugby where the forward players push against each other in a formation (8 vs. 8)
Scrum cap: Protective padded helmet allowed to use in RU
Set piece: Game situation starting from a specific formation or situation (e.g. lineout or scrum)
Smother tackle: the tackler plants their lead foot close to the ball carrier and target ball carrier's arms and the ball
Spear tackle: A dangerous tackle in which a player is picked up by the tackler and turned so that they are upside down. The tackler then drops or drives the player into the ground often head, neck, or shoulder first
SRC: Sports related concussion
Tackle: One or more opposition players [tackler(s)] grasp onto the ball carrier and bring them to ground

1 INTRODUCTION

Rugby Union is a contact team sports, which offers multiple benefits to the participant, but unfortunately, generates simultaneously also relatively high risk for incident of injury (Allender et al., 2006, p. 834; Williams et al., 2013, p. 4). Multiple studies have shown rugby to be linked with head injuries and concussions (Brown et al., 2019, p. 4; Rafferty et al. 2017, p. 969; Roberts et al., 2017, p. 2). Moreover, sports-related concussions have received considerable notice in the literature, primarily since of their alleged association with increased risk of neurodegenerative diseases and long-term cognitive impairments (Hallock et al., 2023, p. 1; Zimmerman et al., 2024, p. 2).

In a game of rugby, players experience a diverse range of mechanical loads due to the dynamic nature of the sport. These loads vary in magnitude, influenced by factors like player speed, mass, acceleration, and the intensity of physical confrontations, encompassing a wide spectrum of mechanical stressors on the musculoskeletal system throughout the game. Fundamental in rugby is to be able to train to withstand and manage these loads to reduce injury risks and enhance performance in competitive scenarios.

Injuries to the neck and head areas are always potentially catastrophic. The necessity of injury prevention interventions is better understood as we get more knowledge about the occurrence and causes of sports injuries. Laws of the game are a critical aspect of approaching the issue, but coaches, trainers and players should play a crucial role in planning the trainings suitable and implementing the fitness with skill levels to minimize the likelihood of injuries happening. World Rugby (2023e) claims that player welfare is their top priority and that there are several strategies to reduce injuries in rugby.

In Finland, there is an average of 600 rugby players, many of whom have started the participation in rugby activities at adulthood. Thus, it is understandable, that the physical basis and the understanding of the game may not be at the same level as someone who has known the sport since childhood. This fact only makes the rugby conditioning more challenging since starting point. Resources and the level of play in Finland are rather moderate, and the amount and type of training, especially in team setting might be often insufficient compared to the demands of the game.

There is a widespread belief among coaches and players in rugby that stakeholders don't have enough understanding to identify head injury symptoms and understand the possible lasting neurological and mental health effects. The necessity for increased education is consistently being pointed out regarding concussions in rugby. (van Tonder et al., 2024, p. 5.)

The Finnish Rugby Union – SRL is a commissioner of this work. SRL is providing information and support during the thesis process.

2 AIM AND OBJECTIVE

This thesis aims to empower Finnish rugby players and coaches with comprehensive knowledge and practical skills to implement evidence-based strategies for preventing head and neck injuries. The centerpiece of this initiative will be the development of a workshop event. The workshop will provide a concise overview of factors contributing to these injuries and equip participants with knowledge of various injury prevention prerequisites specific to rugby. Furthermore, the event aims by working as a catalyst for continuous learning to foster a culture of constant improvement and player safety within the Finnish rugby community. By providing a comprehensive framework and empowering individuals, this thesis aims to make a contribution to the safety and well-being of players at all levels.

A crucial aspect of this thesis is exploring the diverse viewpoints regarding neck area conditioning and its role in injury prevention. By understanding these perspectives, the project has the potential to identify eventual knowledge gaps and tailor its approach to address the specific needs of Finnish players and coaches. Ultimately, this thesis aspires to answer a crucial research question: "Is there anything an individual (player/coach) can actively do to reduce the risk of head and neck injuries when coaching/playing/practising rugby in Finland?" By exploring this question and providing a comprehensive toolkit of knowledge, this thesis aims to make an impact on the safety and well-being of those involved in the sport in Finland.

3 STUDY DESIGN

This thesis has been conducted by the principles of a practice-based methodology. The beginning point for this thesis was a concrete, existing task, which involved a creation of an educational event. As an output result an educational event to the players and coaches was conducted. This practice-based thesis emphasised the creation of evidence based practical knowledge, since the end product is a central component of this thesis itself.

This thesis report includes a theoretical framework as a review article issuing the factors around head and neck injuries in rugby as well as a description and evaluation of the operational component. Data was semi systematically analysed with the principles of a content analysis by categorizing and interpreting the content of the selected studies. In addition to the content analysis, also type of hermeneutic analysis style was used since the author wanted to understand and interpret the meaning of the data within its broader context. The report contributes not only to the practical end-product but also through the insights derived from the analysis of the data in the conclusions in the form of comprehensive summary. Creative work has been described in the implementation part after conclusions. Finally, this thesis report aims to summarize and integrate existing knowledge and research findings, offering insights, interpretations, and some implications in the discussion part.

In essence, data collection in this work aims to serve as a bridge to the output of the practical work. It ensures that the work is not solely based on subjective experiences and is supported by empirical evidence and analysis. Collected data provides evidence, observations, and empirical material that informs and enhances the quality and depth of the work. One purpose was to offer credibility to the practical component of the thesis and help to form the context of the work.

In the data collection, it was crucial to use appropriate data searching tools. Data was gathered through different search engines and online databases, such as Samk`s search engine Finna alongside others such as Google Scholar, PubMed, ProQuest, PEDro, Semantic Scholar, Elsevier and ResearchGate. Aim was to gather a wide, relevant, and updated information to be able to form compound understanding of the topic. Research question helped to define the issues which needed an answer. Research question also guided the author in the data collection process. Sampling could be described as purposive, since the data was gathered using a specific criterion which were related to the research objectives. The author wanted to target individuals with specific experiences and characteristics relevant to the study. When finding information, the researcher used multiple different search term combinations such as “rugby”, “head and neck injuries”, “injury prevention”, “prevalence of…”, “adult rugby”, “neck strength” and “risk factors”. At first no studies were excluded based on year, gender, age, or level of competition. Later, the author focused more on the recent studies and overlooked majority of the studies regarding children and adolescents.

Data was gathered from several injury surveillance and epidemiological studies, articles, reviews, analyses, and reports. A few consensus statements, one symposium-event and doctoral thesis were taken into account when conducting research for this work. Meta-analyses and systematic reviews provided comprehensive and quantitative overview of the topic whereas smaller reviews, and reports could provide additional details and contextual information about understanding patterns and terms concerning head and neck injuries in rugby. Several books were used as a source when doing this oeuvre, especially, when describing the anatomical aspects, and the principles of training and injury prevention theories. World Rugby´s website was useful in finding a basic information about the sport, guidelines regarding training and when investigating the Laws of the game.

Presenting the data in the theoretical framework aims to lead both the reader and the author to a deeper understanding of the topic of head and neck injuries in rugby and the contributing factors around it. Consequently, it helps to constitute a critical reflection and allow better analysis of this work and evaluating the outcomes. By gathering data and information, the author was able to mold the final product to fit to existing theories, practices within the study field and also propose new perspectives to stakeholders based on the findings. By describing data processing steps, transparency is better insured, and aims in facilitating reproducibility of the results and providing a clear understanding of how conclusions and recommendations were made in this practical thesis.

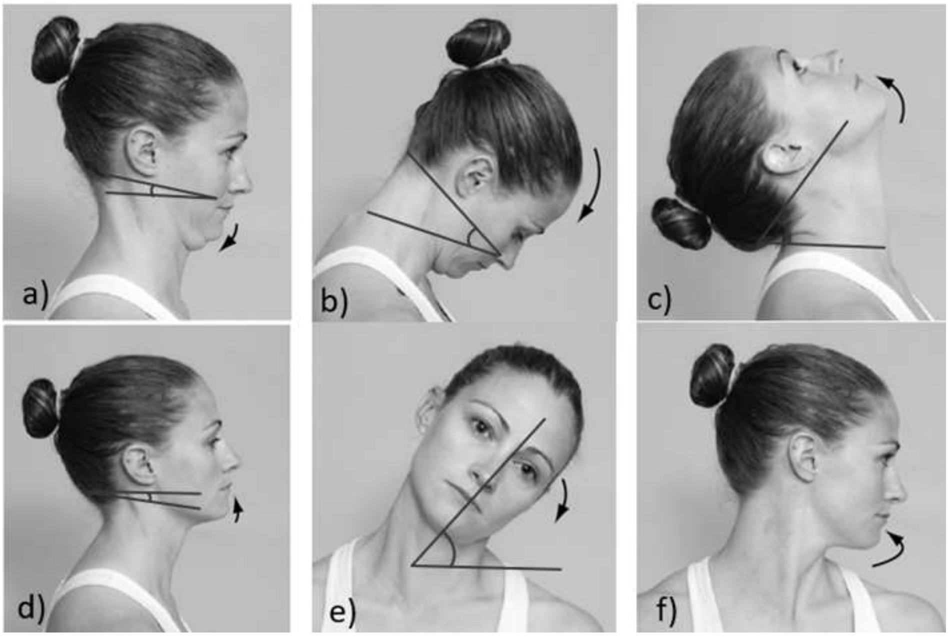
4 CERVICAL AREA

The cervical spine is made up of numerous pairs of joints. It is a place where stability might be sacrificed for movement, rendering the cervical spine particularly vulnerable to damage since it lies between a heavy, mobile head and a stable thoracic spine and ribs. (Magee & Manske, 2021, p. 164.) According to Kukkonen et al. (2001, p. 49) cervical spine has three main functions: it supports and holds the head in place, enables head movements and protects the spinal cord and arteries.

4.1 Movements

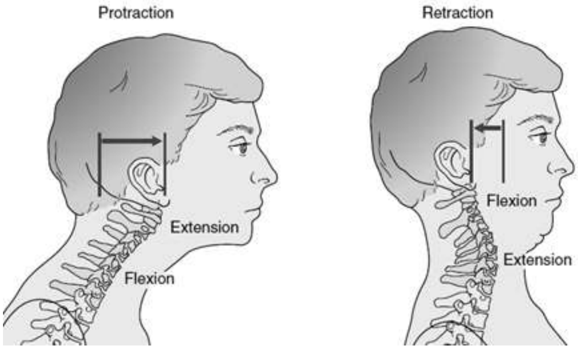
According to (Lark & McCarthy, 2007, p. 887), rugby players require both good peripheral vision and rotational range of motion in the cervical spine area to be able notice the positions of opposition players and avoid being tackled and possibly injured. They continue stating: “The active cervical range of motion of rugby forwards is similar to that of whiplash patients, suggesting that participation in rugby can have an effect on neck range of motion that is equivalent to chronic disability”.

According to Tortora & Derrickson (2017, p. 267-268), in synovial joints there are angular movements of flexion, extension, hyperextension, and lateral flexion. The angle between articulating bones increases or decreases during angular motions. In circumduction the distal end of a body part moves around the proximal with a circular motion. Circumduction is not a single movement, but rather a continuous process of joint flexion, abduction, extension, adduction, and rotation. The basic movements of the cervical spine are illustrated in picture 1.



Picture 1. Active movements of the cervical spine according to Magee & Manske (2021, p. 184) (a) Anterior nodding (upper cervical spine). (b) Flexion (lower cervical spine). (c) Extension (lower cervical spine). (d) Posterior nodding (upper cervical spine). (e) Side flexion. (f) Rotation

When the head is protracted forward, the lower to middle cervical vertebrae is in flexed position simultaneously as upper part of the cervical spine extends. However, when the head is retracted, the lower to middle cervical vertebrae elongate into extension whereas the upper district flexes. (Magee & Manske, 2021, p. 181-182.) Picture 2 illustrates the movements of the cervical spine in protraction and retraction of the cranium.



Picture 2. Protraction and retraction of the cranium (Magee & Manske, 2021, p. 181)

The range of motion of the cervical spine is the determined by multiple factors, including the flexibility of the intervertebral discs, the shape of the articular processes of the vertebral joints, and the play of the ligaments and joint capsules. Active movements of the cervical spine can be divided into upper cervical vertebrae (C0 to C2) and motion that is conducted from the lower cervical vertebrae (C2 to C7). (Magee & Manske, 2021, p. 181-182.) The rotational movement is notable specially in atlanto-axial joint, which turns into flexion-extension movement going down from the C2 vertebra (Kukkonen et al., 2001, p. 50). Mobility of the cervical spine is important since head and neck posture needs to be able to adapt quickly to optimize the position of sensory organs such as eyes and the ears (Portland & DeRosa, 1995, p. 50; Kukkonen et al., 2001, p. 49). Table 1 demonstrates the approximate ROMs in the different parts of the cervical spine.

Table 1. Approximate range of motion for the three planes of movement for the joints of the craniocervical region (adapted from: Magee & Manske, 2021, p. 184)

Joint/region	Flexion & extension	Axial rotation	Lateral flexion
Atlanto-occipital joint	Flexion: 5° Extension: 10° *Total: 15°*	Negligible	~5°

Atlanto-axial joint complex	Flexion: 5° Extension: 10° *Total: 15°*	40°-45°	Negligible
Intracervical region (C2-C7)	Flexion: 35° Extension: 70° *Total: 105°*	45°	35°
Total across crani-ocervical region	Flexion: 45°-50° Extension: 85° *Total: 130°-135°*	90°	~40°

4.2 Generic bony anatomy and soft tissues

Tortora & Derrickson (2017) clarify that a human spine is composed of bones and connective tissue. These structures surround and protect the spinal cord. Normal vertebral column consists of four curves of kyphosis and lordosis. They continue stating that the spine acts as a strong, flexible rod with parts that can move forwards, backwards, sideways, and with rotational movement. Furthermore, they are estimating that the curves of the spine increase endurance, help maintain balance in an upright position, absorb shock and help protect vertebrae from fractures. The atlanto-occipital joint connects the head to the rest of the spinal column which is normally comprised of 26 vertebrae. Spinal vertebrae consist typically of vertebral arch, several processes, and a vertebral body. (Tortora & Derrickson, 2017, p. 215-216.)

The intervertebral discs are located between the vertebral bodies of vertebrae. They act as a shock absorber as well as allow the mobility of the spine. Furthermore, they grant lesser demands for the vertebral bodies, since they distribute stresses through this soft structure. Intervertebral discs consist of an outer layer of fibrous structure – annulus fibrosus – and the innermost substance the nucleus pulposus, which is more jelly-like. (Davatz et al. 2007, p. 12.)

The ligaments are essential to ensure the stability of the spine. Ligament longitudinale anterius is attached to each vertebral body from the anterior aspect starting from the atlas and descending all the way to sacral area. In contrast, the ligamentum longitudinale posterius is locating on the dorsal side of the vertebral bodies. This posterior ligament is attached also to the intervertebral discs and has two distinct layers. Furthermore, there is separate shorter ligament named ligamentum flavum, which connects the laminae of each vertebral segment together as well as the supra- and interspinal ligaments connecting the spinous processes. (Davatz et al., 2007, p. 11; Magee & Manske, 2021, p. 165.) In the cervical region the supraspinous ligament is greatly developed forming an important landmark addressed as the ligamentum nuchae. Viscoelasticity is essential feature for the normal function of the ligaments, allowing them to deform under stress and act against shear forces. (Hall, 2022, Chapter 9, p. 10-11.) Ligaments which connect the axis to the occiput are called the cruciate ligament complex, tactorial membrane, alar ligaments, and apical dental ligament (Porterfield & DeRosa, 1995, p. 106).

Fascia is a dense sheet of connective tissue containing collagen fibres. Fascia separates different muscle groups and tissues allowing separate muscles to slide past each other. It can provide pronounced area of attachment between bones and muscles, and this can be obtained in the neck area as well. (Atkinson, 2013, p. 48.)

4.3 Vertebrae

Typically, the vertebrae vary in size, formation and detail depending on the level of the spinal column. The cervical region is composed of seven vertebrae. The uppermost vertebra is inferior to the occiput called the atlas (C1) named after the mythological Atlas. The atlas is a ringlike bone without vertebral body nor spinous processes. However, the transverse processes and transverse foramina of the atlas are relatively massive. The second cervical vertebra (C2) is called the axis. It has its own characteristics: a toothlike process called the dens projects superiorly with the atlas making one of the few pivot joints of the human body creating rotational movement to the cervical spine. This joint is called also the atlanto-axial joint. The vertebral bodies of the cervical vertebrae (C2-C7) are somewhat smaller than from the rest of the spine. In contrast, the vertebral foramina are large since the spinal column needs to be able to travel through the passage. Cervical vertebrae contain one vertebral foramen called spinous process and two transverse foramina. The transverse processes include foramen in which the vertebral arteries are travelling. (Tortora & Derrickson, 2017.) Between C3 and C7, the vertebral shape remains relatively consistent. When descending, the vertebrae gradually enlarge to accommodate the growing load, and the spinous processes elongate. (Davatz et al., 2007, p. 11.) The cervical spine from C1 to C7 comprises 14 facet (apophyseal) joints. The superior facets of the cervical spine are oriented upward, backward, and medially, while the inferior facets face downward, forward, and laterally. (Magee & Manske, 2021, p. 165.)

4.4 Muscles

Skeletal muscles are the voluntary muscles responsible for movement and stability. Muscles attach to bones via tendons, enabling us to control actions consciously. Muscles consist of bundles of muscle fibers, containing myofibrils composed of sarcomeres. As sarcomeres within muscle fibers contract, the entire muscle shortens, generating force and causing movement at the joints. Neck muscles play a vital role in supporting the head's weight and facilitating various motions. (Marieb & Hoehn, 2019, p. 283; Tortora & Derrickson, 2017, p. 298.) The cervical region serves as an attachment point for muscles of the shoulder girdle and is bearing the load and absorbing forces generated during the functioning of the upper limbs (Jull & Falla, 2017, Chapter 23, p. 3).

Skeletal muscles muscle fibre types are classified into two main categories, slow-twitch (Type I) and fast-twitch (Type IIa-IIx) fibers. These distinct muscle fibre types enable the human body to accomplish different kinds of tasks from low intensity to short, burst activities. Type I fibers are more resistant to fatigue being able to contract over extended periods of time with little decrement in force production, whereas type II muscle fibers demonstrate more high rapid forces production capabilities with quicker fatigue. (Hopwood et al., 2023, p. 223; Marieb & Hoehn, 2019, p. 280.) Many muscles in the body consist of a blend of different fiber types, a composition influenced by factors such as genetics, hormonal profile, training, and the specific function of the muscle

(Kraemer et al., 2021, Chapter 5 summary). Muscle fibers have the ability to adapt to varying demands by altering their size or fiber type composition. This adaptability forms the physiological foundation for numerous physical therapy interventions aimed at enhancing strength and endurance. (Scott et al., 2001, p. 1810.)

In muscle work, different types of contractions define how muscles generate force and move. Isotonic contractions involve consistent muscle tension while the length changes, divided into concentric and eccentric phases. Concentric contractions occur when the muscle shortens while generating force. Eccentric contractions, however, happen as the muscle lengthens under tension. Isometric contractions, on the other hand, involve muscle tension without a change in length. Each type of contraction plays a unique role serving either power, control, or stability. (Marieb & Hoehn, 2019, p. 298.) Most movements entail a combination of eccentric and concentric muscle contractions, although the relative proportions of each contraction type vary (Ansari et al., 2023, p. 288).

The musculoskeletal system of the cervical spine is one of the most intricate in the human body. The cervical muscles exhibit significant morphological diversity to enable and regulate the extensive range of head movements. (Conley et al., 1997, p. 2109.) Optimal neck function necessitates coordination between the deep and superficial muscles. The superficial muscles contribute to the gross movements of the head and the upper extremities whereas the deep musculature protects the cervical spine providing segmental support and stable posture. (Jull & Falla, 2017, Chapter 23, p. 3; Reddy et al., 2022, p. 2.) The neuromuscular system is crucial in diverting potentially harmful forces away from specific regions of the cervical spine. Muscles channel these forces through specialized connective tissues via their attachments to different bony levers. (Portfield & DeRosa, 1995, p. 12-13.)

Multiple neck muscles are involved in maintaining the balance by being able to move the head accordingly. Furthermore, adequate neck muscle control crucial in eye movements. (Kukkonen et al., 2001, p. 49; Tortora & Derrickson, 2017, p. 349.) In addition to indicating the importance of the neuromuscular system as a whole, the author is acknowledging some of the essential muscles specifically in the following subheading. The full tables of muscles with their actions, origin & insertion points, and innervations are expressed thoroughly in appendix 1.

4.4.1 Features of clinically relevant muscles

Neck musculature not only support the head's weight and maintain proper posture but also contribute to a wide range of movements involving the neck and upper spine. Clinically, many of these muscles are crucial in diagnosing and treating various neck and head related issues such as strains, injuries, whiplash, postural imbalances, and neurological conditions affecting the cervical spine. (Magee & Manske, 2021, p. 73-78.)

The trapezius muscles work in coordination with other muscles of the shoulder girdle and neck to facilitate various movements, contributing to posture, stability, and mobility of the upper body. It connects the shoulder area to the vertebral column having attachment points at the occiput, ligamentum nuchae, thoracic spinous processes and spine of the scapula, acromion, and clavicle. Furthermore, it has a role in stabilization of the head. (Porterfield & DeRosa, 1995, p. 54.) Superior portion of the trapezius is involved in elevating the shoulders and in assisting extending the head backward. Middle portion attaches between C7-T12, being responsible for retraction of the scapulae. The inferior portion (lower part of C7-T12) depresses the shoulders and scapulae. (Ourief et al., 2023, Structure & function.) Faria et al. (2017, Conclusions) claim that the trapezius muscle shows decreasing muscular activity after multiple tackle impacts in rugby.

The sternocleidomastoid muscle (SCM) is one of the thirty muscles affecting to the upper body movements. It has multiple functions and dual innervation. Furthermore, it plays a significant role in maintaining the posture of the head, neck, and body. (Bordoni et al., 2023, Introduction.) SCM has numerous actions and individualized functions in addition to rotation: upper part causing extension of the upper spine, lower part flexion. SCM is an important muscle clinically since it usually in one of the anterior soft tissue structures injured during an acceleration injury. (Porterfield & DeRosa, 1995, p. 56; Tortora & Derrickson, 2017.) SCM muscle is usually containing both slow and fast twitch muscle cells (Cvetko et al., 2012, Abstract).

Scalene muscles provide important functions to the first upper ribs, head, and cervical spine. They support neck movement and respiration. The anterior and posterior scalene muscles serve an excellent position for dynamically stabilizing the cervical spine in coronal plane. Since the scalenes are originated from different transverse processes from the cervical vertebrae, they have the capability to laterally flex the head and provide some rotational movement also. Scalene and levator scapulae muscle orientations help to generate stabilization against anterior and posterior shear forces. (Porterfield & DeRosa, 1995, p. 59.)

The semispinalis cervicis and capitis muscles are part of the deep muscles in the back of the neck and upper back. They are one the most important extensor muscles of the occiput and cervical spine. The semispinalis cervicis helps extend and rotate the cervical spine, aiding in keeping the head in an upright position and allowing controlled movements of the neck. Meanwhile, the semispinalis capitis assists in extending and rotating the head, contributing to head movement and stability. Both muscles work synergistically with other neck and back muscles to provide stability to the cervical spine, support the weight of the head, and allow for coordinated movements, highlighting their significance in posture maintenance and controlled neck and head motions. (Porterfield & DeRosa, 1995, p. 60.)

Suboccipital muscles are arranged by the small muscles posterior-inferior to occiput, atlas, and axis. The muscles of this area are also referred as the suboccipital triangle muscles. Rectus muscles form the midline of the triangle whereas obliquus capitis muscles lie more laterally. Suboccipital muscles have the ability to move the upper cervical spine complex independently of the lower part. (Porterfield & DeRosa, 1995, p. 61.)

Anterior colli & capitis muscle group covers the anterior aspect of the cervical vertebrae. They are often referred as “deep flexors of the head”. Longus colli & capitis muscles can act as flexors and anterior sagittal rotators. The gap between opposite sides longus colli muscles is one of the few bony regions in the spine without muscle attachments. Rectus capitis muscles are coursing anteriorly and laterally between atlas and the occiput. These small muscles contribute more to the proprioception rather than working as prime movers of the head. (Porterfield & DeRosa, 1995, p. 62.)

4.4.2 Muscle spindles

Muscle spindles are specialized sensory receptors found within most skeletal muscles. They are largely involved in proprioception – the body´s sense of its own position and movement in space and thus involved also in the scheme of injury prevention. They are sensitive to changes in muscle length and enable precise head movements and help maintenance of balance. (Tortora & Derrickson, 2017, p. 555.) The suboccipital and deep cervical muscles present the highest muscle spindle density of the whole body. The suboccipital muscles have approximately 150 to 200 muscle spindles per gram of muscle tissue. Some of the highest concentrations of muscle spindles /g/muscle tissue are in the deep muscle fibers of the paraspinal muscles in which spindle density can range up to 500 spindles /g/muscle tissue. (Jull & Falla, 2017, Chapter 23, p. 3; Porterfield & DeRosa, 1995, pp. 47, 77; Reddy et al., 2022.)

The neck is linked through reflex connections to both the vestibular and ocular systems. Any changes in cervical afferentation can result in symptoms such as instability, dizziness, or visual disturbances. Furthermore, since the muscles in the cervical spine contain numerous muscle spindles, they play a significant role also in neck muscle endurance by partaking in afferent motor functionality. (Jull & Falla, 2017, Chapter 23, p. 3; Reddy et al., 2022, p. 10.)

To sum up, the high muscle spindle density in the cervical region is essential for maintaining posture, balance, fine motor control, reduced injury risk, and eye-head coordination. This unique feature of the cervical muscles allows for the stability and precision of head movements, making it possible for us to interact effectively with our environment, whether on and off the rugby field.

4.5 Neurological fundamentals

The nerves in the cervical spine emerge from the spinal cord through openings between the vertebrae and are named according to the vertebra above which they exit. Consequently, there are eight (C1-C8) cervical nerves They form nerve plexuses which branch out to innervate muscles, skin, and organs. (Magee & Manske, 2021, p. 168; Tortora & Derrickson, 2017, p. 456.) Cervical plexus consists of a network of nerves formed by the anterior branches of the first four cervical spinal nerves (C1-C4) with contributions from C5. These nerves innervate structures in the neck, shoulder, chest, and some areas of the head. The cervical plexus plays a crucial role in sensory perception, motor function, and autonomic regulation in regions such as the skin of the neck, parts of the ear, scalp, and shoulder, contributing to both sensation and movement. (Tortora & Derrickson, 2017, p. 456-457.) A network of nerves formed by the anterior rami of the lower cervical nerves (C5-C8) and the first thoracic nerve (T1) constitute the brachial plexus complex. The brachial plexus plays a pivotal role in controlling motor functions and transmitting sensory information, enabling movement and sensation in almost the entire shoulder and upper limb areas. It comprises multiple roots, trunks, divisions, cords, and branches. The brachial plexus has five significant terminal branches: the musculocutaneous nerve, supplying muscles in the anterior arm; the median nerve, controlling anterior muscles of the arm and some muscles of the hand; the ulnar nerve, governing multiple hand movements and anteromedial forearm muscles; the radial nerve, overseeing the muscles on the posterior side of the arm; and the axillary nerve, innervating the deltoid and teres minor muscles. (Tortora & Derrickson, 2017, p.458.) Accessory nerve (cranial nerve XI) is a motor nerve and unique since it has both a cranial and a spinal component. The cranial part emerges from the brainstem, specifically from the medulla oblongata and the upper cervical spinal cord (C1-C5), while the spinal component originates from the spinal cord. This nerve supplies the sternocleidomastoid muscle, allowing head rotation and flexion, and the trapezius muscle, facilitating movements of the shoulders and scapula. (Tortora & Derrickson, 2017, p. 517.)

To conclude the previous, functioning nerves in the head and neck are crucial for coordinating and executing movements. These nerves control the muscles involved in head and gross neck movements, allowing us to turn, tilt, and flex the head, as well as perform various actions as well as performing more precise and settled actions like facial expressions, swallowing and speaking. Dysfunction or damage to these nerves can lead to sensory deficits and limitations in head and neck movements, causing stiffness, weakness, or loss of control over these essential actions and overall mobility.

5 RUGBY

Rugby Union (RU) is a contact ballgame played by almost ten million people around the world. Rugby World Cup tournament which is played once in every four years pertains to be one of the planet’s biggest sporting events. Furthermore, rugby seven´s game format is played in summer Olympic games. One of distinguished factor about rugby is that is has a reputation as being a game for all body shapes and sizes. Moreover, rugby is one of the only contact-collision sports where the rules for women and men are the same. World Rugby´s vision is driving a sport for all-true to its values which are integrity, respect, solidarity, passion, and discipline. Number one priority for World Rugby is the player welfare from the grassroots to the elite level of the game. (MacQueen & Dexter, 2010, p. 139; World Rugby, 2021d, p. 6-27.)

The game's objective is to score as many points as possible against an opposing team by carrying, passing, kicking, and grounding the ball, according to the laws of the game, its sporting spirit and fair play. The contest for possession of the ball is one of rugby's key features. These contests occur throughout the game and in a number of different forms: in contact, open play and when play is re-started at scrums, lineouts, kick-offs, and restart kicks. As one team attempts to maintain continuity of possession, the opposing team strives to contest for possession. Each team has 15 players in the playing area during play and ongoing play time is 80 minutes. Rugby ball is oval shaped and made of four panels. (World Rugby, 2023c, p. 7-38.) In rugby, it is recommended to wear a mouth guard, and some players choose to wear approved head gear or padded equipment under the shirt (World Rugby 2023a).

5.1 Rugby in Finland

Rugby in Finland has a relatively short history compared to many other countries. Some versions of the game were already played in the sixties (Lindfors, 2012). Apparently, more traditional version of rugby union was introduced in the early eighties by a French teacher when he presented the game to the pupils in Helsinki (Flörchinger, 2002, p. 13). The Finnish Rugby Federation (Suomen Rugbyliitto, SRL) was officially established in 1999 and is a member of World Rugby, Rugby Europe, and Finnish Olympic Committee. The federation is responsible for organizing the sport in Finland, including the national men's and women's teams. (Suomen Rugbyliitto, 2024, p. 1.)

Rugby in Finland is a marginal sport with poor conspicuousness. The sport has not grown steadily in recent years, since the number of competition licenses developed positively until 2017 after which the number is reduced to the current approximately 600 annual licenses. Globally, rugby is a growing sport, especially among women and girls. In Finland, approximately one-third of the participants are women and girls. (Suomen Rugbyliitto, 2024, p. 2.) In Finland, rugby is currently played and practiced officially at least in sixteen different localities. In the 2023-2024 season, five different series were played nationally in rugby union. In addition to this, rugby sevens´ series and Snow Rugby tournament were played. (Suomen Rugbyliitto, n.d.) There are four national teams in Finland − women´s and men´s side playing both rugby sevens´ and fifteens´. The Finnish national women's 15´ team is currently ranked 34th in the world by World Rugby whereas the Finnish national men's 15´ team stands in place 78. Both teams have never qualified for the Rugby World Cup tournament. (World Rugby, 2024i.)

According to SRL (2024, p. 5) the development of the sport requires the development of expertise in the sport and the knowledge of the people working among it. Furthermore, adequate training and increasing skills are a key factor of players well-being and safety. Federations aim is to actively respond to the need of educational activities, which for their part enable both clubs and individual development and individuals and enhance the development of rugby-related skills.

5.2 Game situations

Undoubtedly, rugby is a highly versatile sport in which the strength, agility and functionality are needed in all different phases of the game from the whole body – including the cervical spine area. Rugby union players experience a variety of distinct extrinsic forces in multiple different game conditions. Few common game situations are illustrated in picture 3.

Picture 3. a) tackle b) ruck c) scrum (World Rugby, 2023c, pp. 70, 76, 105)

A tackle situation is depicted in picture 3 a), in which one or more opponents hold and bring the ball-carrier to the ground, as defined by World Rugby (2023c, p. 70). The defending team employs tackles to halt the attacking team's progress and seizes the opportunity to vie for ball possession. A tackle is truly one key component in a game of rugby, and it can be considered being highly technical and physical skill. The tackler should consider how they are preparing for the contact – adopting the body position to strong, stable, and low. The head position is important – it should never be in front of the ball carrier. The arms should be used to ‘wrap’ around the ball carrier. The ball carrier should carry the ball in both hands and to prevent taking hand contact to ground when landing. Elbows should be placed to the sides and the chin should be tucked to the chest to prevent “whiplash” -movement of the head and neck – the contact to the ground should be taken first through the buttocks and then via the shoulder area. Head contact to the ground should be avoided. (World Rugby, 2023e.) According to Paul et al. (2022, p. 16), there is an average of 156 tackles in a game of rugby union, with forward players experiencing slightly more (12.8) tackles per game compared to backline players (7.6) on average.

A ruck situation (picture 3b) occurs usually after a tackle situation and allows players to compete for the possession of the ball. A ruck is formed when at least one player from each team is in contact, on their feet and over the ball. The players involved in the ruck are not allowed to play the ball with their hands at this point. Possession may be won either by rucking or by pushing the opposing player(s) off the ball. (World Rugby, 2023c, pp. 76-79.) Six Nations statistical report (World Rugby, 2021h, p. 2) reveals that the total number of rucks in elite level game is on average 197 pieces per game.

A scrum´s (picture 3 c) purpose is to restart play with a contest for possession after a minor infringement or stoppage. Possession may be gained by pushing the opposition backwards and off the ball. Eight forward players (props, hooker, second- and back row positions) from both teams bind together in formation. (World Rugby, 2023c, pp. 102-109.) There are approximately 10 scrums in a game of rugby in elite level (World Rugby, 2021h, p. 2). The scrum battle stands as a fundamental aspect of a rugby match. Achieving success in this phase relies on optimizing joint angles and individual force production, coupled with the coordinated efforts of the team as emphasized by Green et al. (2019, p. 6). MacQueen & Dexter (2010, p. 140) state in their paper: “The scrum can be dangerous and result in serious injury, specifically to the cervical spine."

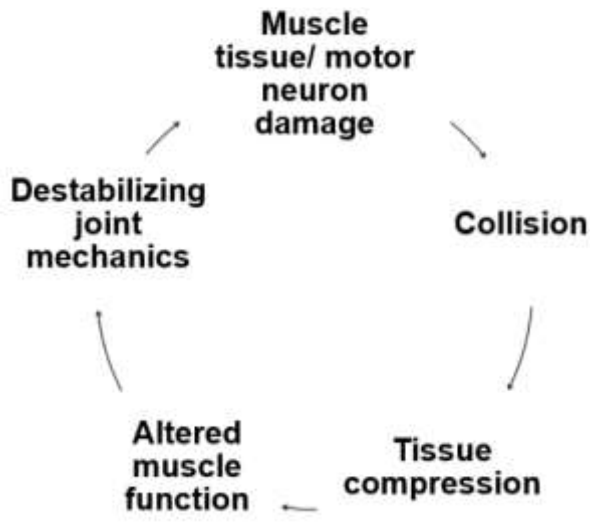
5.3 Biomechanics

Kinematic study in rugby involves information about the motions of players, assessing the forces, velocities, accelerations, and impacts experienced by athletes during collisions and other movements. Biomechanical study includes investigation on both the internal forces produced by muscles and the external forces acting on the body It involves assessing experiences during various game situations such as tackles, scrums, kicking, and sprinting. Biomechanical analysis can assist in understanding optimal body positions, joint angles, and techniques when performing these activities in the field. (Hall, 2022.) Kinematic data analysis can help in the development of game strategies and tactics, optimizing player performance and team dynamics. (Daneshvar, 2011, p. 2.)

The force-velocity relationship describes how the force an individual can produce is inversely proportional to the velocity of movement. As movement speed increases, the ability to generate force decreases, and vice versa. Power is arguably the most remarkable physiological variable in sports since the ability to generate high forces at high speeds is pivotal in almost all domains of athletic performance. Power and velocity become the most important factor in performances such as sprinting, jumping, kicking, and striking, whereas a rugby player is likely to produce near maximal forces in activities such as scrummaging. (Hall, 2022, Chapter 3: 1/1; Jones et al., 2013, p. 200.) Understanding the force-velocity relationship is significant for rugby players as it influences their performance. It can help in design position-specific training that aligns with the demands of each role.

External and internal workloads are concepts that are used to track and manage the physical demands placed on players. External workload is any external stimulus applied to the athlete that is measured independently of their internal characteristics. It may include factors such as total running distance and the number and intensity of sprints and collisions. Externally generated forces might be adjusted by modifying equipment, playing surfaces, or sport regulations. Internal workload is the physiological and psychological response in an individual following the application of an external load including for example ratings of perceived exertion and heart rate. Internally generated forces necessitate considering an individual athlete's characteristics and abilities, including muscle strength, endurance, flexibility, motor control, joint range, biomechanics, and proprioception. (Gabbett, 2016, p. 9; Warden, 2017, Chapter 3. p. 3/24.)

Injuries can arise from an energy transfer surpassing the body's capacity to uphold its structural or operational integrity. The likelihood of injury relies on factors such as the magnitude and distribution of force, its direction, and the biomechanical characteristics of the body structures receiving this energy transfer. (Quarrie & Hopkins, 2008, p. 1713-1714.) The body generates significant counteracting forces against spinal torques from external loads through coordinated muscle activation, leveraging the strength of the core muscles like the abdominals, obliques, and erector spinae. This activation creates stability around the spine, enabling the body to distribute and neutralize applied forces effectively. Coordinated movement patterns and proper biomechanical techniques, alongside regular strength training, further optimize force generation while minimizing stress on the spine is crucial for resisting external torques and maintaining spinal integrity. (Comerford, 2012; Hall, 2022.) Doran & Naidoo (2021, p. 5-6) describe the musculoskeletal system's rapid and dynamic response to external forces in rugby is crucial for providing structural tensegrity and ensuring stability, to tolerate the impact experienced on contact engagement. Dane et al. (2021, p. 7) comment that collision field athletes require a blend of intermittent endurance, repeated sprint ability, collision-based exertions, decelerations, and accelerations. Moreover, they note that contextual elements like player position, opposition, scoring, match quarter, and competition level significantly impact the physical demands experienced during game play. In picture 4, Doran & Naidoo (2021) suggest a theoretical model for the relationship between the number of tackles in which a player engages in acute and chronic fatigue, magnitude of impact (energy load), markers of muscle damage (microtrauma) and how this relationship interacts with the tackle injury risk (tolerance overload and reduction) and tackle performance.



Picture 4. Theoretical model describing the aetiology of repetitive collisions on contact in rugby union (adapted from Doran & Naidoo, 2021, p. 6)

Tackling analysis in rugby poses significant biomechanical challenges due to the dynamic and multifaceted nature of the action. Each tackle involves diverse variables such as the speed and angle of approach by both the tackler and the ball carrier, their relative body positions, and the unpredictability of the collision dynamics. Additionally, human movement variability adds complexity, as players execute tackles with different techniques and body positions, making it hard to standardize analysis. (Seminati et al., 2017, p. 19-20.) The frequency and proportion of tackle activity has been shown to vary across playing standards and age categories (Till et al., 2023, p. 1139). The biomechanical aspects vary based on whether the tackle employs the dominant or non-dominant shoulder. Prior to impact, muscle activation readies the tackler for the collision, while force platforms evenly distribute ground reaction forces. The movement of the neck by the tackler during a tackle event involves simultaneous flexion, lateral bending away from the shoulder in contact, and rotational motion. (Seminati et al., 2017, p. 14-18.)

To gain more knowledge about the forces acting on to the players, an Instrumented Mouth Guard technology has been taken in to use in recent years. They provide insight about head acceleration event frequencies and magnitudes, hopefully providing data for the management of chronic load and giving tools to injury prevention. According to Bussey et al. (2023b, p. 4) a threshold for high magnitude head acceleration is 30 g. According to Kaplan et al. (2008, p. 91) the force of 4500 N can cause a compression injury to the vertebral body, whereas a 2000 N of force can lead up to ligamentous injury to the cervical spine. The author has collected data from various sources in table 2 regarding the forces exerted in rugby scheme.

Table 2. Physical loads acting in rugby

Game situation	**Load**	**Information**	**Reference**
Tackle	5000 N	Simulation tackle research. Sample: 15 male participants. Study did not include the movement of the ball carrier.	Seminati et al., 2017, p. 5
	1286 N-1998 N	Teckscan® pressure in-soles, force plates were used to measure the forces.	Faria et al., 2017, Abstract
	1997 N	Participants tackled a 45 kg tackle bag. 35 participants, community level. Force measured from the tackle bag.	Usman et al., 2011, Abstract
	>40 g<	Head acceleration event incidence of elite rugby union players, Instrumented mouthguards (iMG) technology	Tooby et al., 2023, p. 8
	34-66 g	Prospective, observational cohort study, 328 male rugby players from four levels. iMGs.	Bussey et al. 2023b, p. 9
Ruck	>40 g	Head acceleration event incidence in elite RU players, using Instrumented mouthguards (iMG) technology	Tooby et al. 2023, p. 8
	22-78 g	Prospective, observational cohort study, 328 male rugby players from four levels. iMGs	Bussey et al. 2023b, p. 9
Scrum	15 000 N	Review article. The force is describing the force to the front row.	Kaplan et al., 2008, p. 91
	~1700 N	Scrummaging machine simulation (external load is mainly acting at the shoulders) - two participants	Cazzola et al., 2017, p.9
	2458 ~ 4493 N	Review article.	Green et al. 2017. p. 4

Mechanical activation of the nociceptive system in the cervical area is important from the standpoint of injuries since mechanical stresses can result in depolarization of the nociceptors. Sufficient magnitude of compression and tension will result to depolarization on this receptor system. (Porterfield & DeRosa, 1995, p. 55.) Essentially, these mechanical stresses can cause the nerves responsible for sensing pain to become activated, potentially contributing to injury or pain sensations in the cervical region. Understanding these thresholds is vital in assessing the risks associated with mechanical stresses and their potential impact on cervical spine health and injury prevention strategies.

Seminati et al. (2017, p. 5) suggest that there is still insufficient data available regarding the forces, muscle activations, movements, and stresses on anatomical structures resulting from various rugby contact events and that this limited understanding of precise anatomical loading patterns and injury mechanisms has likely hindered the development of effective interventions for preventing injuries related to tackles.

6 SPORTS INJURIES

Injuries in sports can happen during competition or training and impact various musculoskeletal connective tissues. These injuries can be classified as either acute or overuse, depending on the mechanism and symptom development. (Brukner, 2017, Chapter 3: p. 1/24; Jones & Kingston, 2013, p. 185.) A sports injury can be classified as anything from the emergence of a new symptom during training or competition to discontinuation of participation requiring medical attention (Jones et al., 2013, p.182). Injury classification can function as a cornerstone for evidence-based approaches in injury prevention. This classification system facilitates the identification of specific risk factors associated with different injury types, enabling the implementation of targeted interventions, and minimizing injury risks through tailored conditioning. Moreover, injury classification can guide alterations to policies and rules within the sport. (Finch & Cook, 2014, pp. 4-5.)

6.1 Rugby incidents

The literature seems to be somewhat consistent on the overall injury rates in elite rugby. World Rugby´s annual review of injury surveillance revealed the match injury rate being 71 injuries per 1000 played match hours, equivalent to an average of 2.8 time-loss injuries per match in men’s side. Females overall match injury incidences was 61/1000 played-match hours, translating to 2,4 injuries suffered per match in elite women´s rugby. Women´s mean match injury severity was reported to be higher than men´s. (World Rugby, 2023f, pp. 6, 10.) According to a meta-analysis of studies on match and training injuries in elite men's rugby union, the overall incidence rate of injuries in matches was 91 per 1000 hours (Williams et al., 2022, p.1139). The author found no reliable meta-analyses in the study of women´s rugby. Studies that were available showed injury incidences from women´s elite rugby union varying from 19,6 to 61 per 1000 match hours. This indicates overall match injury incident occurrences being lower in women´s game. (Fuller & Taylor, 2023; Gabb, 2018; King et al., 2022; Starling et al., 2023.)

The Rugby World Cup is a premier international tournament for both men and women played once in every four years. Injury surveillance studies conducted during tournaments like the Rugby World Cup hold paramount importance due to their multifaceted benefits. One significant advantage lies in the ability to compare injury data between genders and player positions as shown in table 3. The most recent information from Rugby World Cups is from the women's tournament of 2021 (played in 2022) and the men's tournament data from 2019. The study of the 2019 men´s Rugby World Cup reports an overall injury incidence of 79.4 match injuries per 1000 player-match-hours. The most common locations of injury reported to lower limb area (46,9 %) and to the head/face cervical spine area (26,6%) while the concussion (15,4 %) was the most common specific injury type. The act of tackling (28.7% as tacklers and 19.1% as those being tackled) accounted for 47.8% of all injuries in RWC 2019, showcasing a continued increase in the share of injuries attributed to this action. (Fuller et al., 2020, p. 1.) Women's Rugby World Cup 2021 injury surveillance study reveal that there was an overall injury incidence of 44,2 match injuries per 1,000 player-match-hours. The most common specific injury sustained by players was concussion (13.0%) as demonstrated in table 3. The most common match event leading to injury were tackling (27,5%) or being tackled (40,0 %). Findings suggest that the injury profile for women's rugby is similar to that of men's rugby, with tackles being the most common mechanism of injury. (Fuller & Taylor, 2023, p. 5-10.)

Table 3. Match injuries (%) as a function of injury type, location and playing position at **men´s RWC 2019** and **women´s RWC 2021** (adapted from Fuller et al., 2020, p. 3; Fuller & Taylor, 2023, p. 10)

Injury type	**Backs**	**Forwards**	**All**
Concussion	**15,2** **17,6**	**15,6** **7,4**	**15,4** **13,0**
Bone injuries	**10,1** **5,9**	**3,1** **7,4**	**7,0** **8,7**
Joint (non-bone) injuries	**27,8** **52,9**	**31,3** **77,8**	**29,4** **65,2**
Muscle/tendon injuries	**38,0** **17,6**	**34,4** **7,4**	**36,4** **10,9**
Skin injuries	**1,3** **0**	**4,7** **0**	**2,8** **0**
Pain	**3,8** **0**	**3,1** **0**	**3,5** **0**
Other	**3,8** **5,9**	**3,1** **0**	**3,5** **2,2**
Injury location	**Backs**	**Forwards**	**All players**
Head/face/ neck/cervical spine	**25,3** **23,5**	**28,1** **11,1**	**26,6** **17,4**
Upper limb	**16,5** **23,5**	**20,3** **37,0**	**18,2** **30,4**
Trunk	**7,6** **5,9**	**9,4** **3,7**	**8,4** **4,3**
Lower limb	**50,6** **47,1**	**42,2** **48,1**	**46,9** **47,8**

Usually, soft tissue injuries make up over 50% of all rugby-related injuries. These injuries encompass musculotendinous strains and tears, as well as ligament sprains and tears, hematomas, and contusions. (Kaplan et al., 2008, p. 89.) In elite male match scenarios, the head (16.7%) emerges as the predominant site for specific injury. Among neck injuries in Rugby Union (RU), cervical facet joint sprain, neck muscle strain, and cervical nerve root/brachial plexus neuropathy are notably frequent. While cervical nerve root injuries and concussions rank among the most common injuries, shoulder dislocation/instability led to the highest number of days absent due to injury. (Brooks et al., 2005, p. 765; Swain et al., 2010, p. 386; Williams et al., 2022.) The playing level significantly impacts the incidence of injuries in rugby union. Professional and semi-professional rugby, are associated with a higher risk of injuries compared to amateur levels. (Brooks et al., 2005, p. 761; Burger et al., 2020; Williams et al., 2013.)

6.1.1 Cervical spine and head injuries

The cervical spine is crucial as it encases and safeguards organs and essential structures necessary for maintaining life. Injuries to the cervical spine can span from minor issues to severe, life-threatening situations. These injuries can result from excessive flexion, extension, or rotation of the neck beyond its normal range of motion, often during forceful tackles or awkward falls. (Eckner et al., 2014, p. 8; Ludwig & Streveler, 2016, p. 107.) Forces generating an axial load and compression to the cervical area, significantly heighten the risk of spinal injury (MacQueen & Dexter, 2010, p. 141; World Rugby, 2023e). Disc herniations might occur due to either trauma or stress, with common sites of protrusions typically found between the fifth and sixth, and sixth and seventh cervical vertebrae in the neck region (Hall, 2022, Chapter 9: p. 34-36/48). In RU, neck injuries can lead to symptoms like neck pain, limited mobility, deformity, neurological issues (such as sensory or motor loss), changes in mental state, or subsequent injuries. The occurrence of neck injuries varies from 0.3 to 9.2 per 1000 player hours among diverse player populations. (Swain et al., 2010, p. 384, p. 388.) Table 4 illustrates an overall picture of possible injuries to the cervical spine area with variable mechanisms of injury and signs and symptoms.

Table 4. Cervical spine injuries (adapted from Ludwig & Streveler, 2016, p. 110-114)

Injury	Mechanism of injury	Signs and symptoms	Prevention strategies
Muscle strain and sprains	Accident or whiplash, straining while carrying a heavy object, lifting weights, falling from a height	Pain with neck movement, stiff neck, headache, muscles soreness, difficulty of sleeping	Improve posture, neck stretching and strengthening
Vertebra fracture	Axial loading, axial load with rotation, hyperextension	Cervical pain, extremity pain, numbness in extremities, decreased strength in extremities, decreased movement in neck, muscle spasm	Using proper tackling techniques, wearing seatbelts, avoiding diving into shallow water
Spinal cord damage	Axial load, displaced vertebral fracture, motor vehicle accident, falls, blow to the spine, severe whiplash, disc injury, acts of violence	Inability to move limbs, initial severe pain, loss of bladder/bowel functions, signs and symptoms vary depending on the level of the cervical cord damage	Wearing appropriate sports equipment, using proper tackling techniques, wearing seatbelts, avoiding diving into shallow water

Burners and stingers	* See picture 5	Burning or tingling sensation around the neck, down the arm, or into the hand; numbness or tingling surrounding the arm, but only affects one arm; this does not follow dermatomal pattern, and may cause muscle weakness or point tenderness over Erb´s point	Technique, shoulder pads
Cervical disc pathology	Neck flexion with rotation, repetitive movement, axial load	General neck pain, pain radiating down the arm to the hand, decreased sensation in specific areas of the upper extremities, decreased reflexes in area, signs and symptoms reproduced with neck flexion or neck compression, weak arm, or hand muscles	Not available
Spinal stenosis	Congenital or any change in vertebrae, osteophytes, bone spurs, disc pathology, tumors, hemorrhage	Possibly symptom free or pain down the arm, sensory changes like burning and tingling into the arm and hand, motor changes such as decreased strength, muscle atrophy	Not available

In rugby, cervical spinal cord injuries typically occur due to severe neck flexion, with or without rotation or hyperextension of the C4, C5, and C6 vertebrae (Kaplan et al., 2008, p. 91). A rate of catastrophic cervical spine injuries (CCSI) ranges from 1.4 to 7.2 per 100 000 player-hours. Among elite RU players, there's a moderate amount of evidence suggesting a CCSI rate of 4.1 per 100 000 player-hours. The scrum activity contributed to 35 to 51% of the total reported CCSIs. (Hutton et al., 2016, pp. 1, 723.)

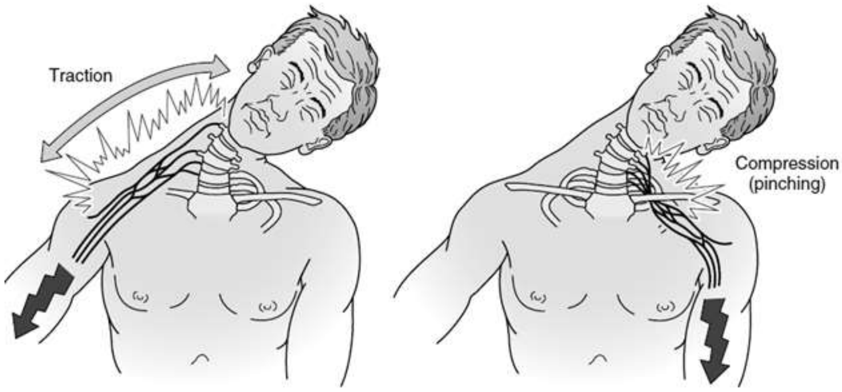
Like many other contact sports, rugby carries a relatively high risk of concussions. Brain injuries occur due to the displacement and distortion of neural tissue. Symptoms may include, but are not limited to, loss of consciousness, headache, dizziness, confusion, memory problems, nausea, blurry vision, difficulty maintaining balance, sensitivity to light and noise, and difficulty concentrating. The acceleration of the skull leads to swift deformation of brain tissue. These forces strain points within the brain, potentially resulting in axonal stress, neuroinflammation, and a cascade of neurological metabolic changes. (Edwards et al., 2023, p. 1569; Tortora & Derrickson, 2007, p. 506.) Numerous studies have consistently identified rotational motion and the resultant shear deformation as the primary mechanism behind concussion injuries. This phenomenon arises due to the notice that the brain exhibits a higher sensitivity to rotational stress compared to linear stress. (Tierney & Simms, 2017a, p. 2.)

Head injuries often stem as a result from the collision between the tackler and the ball carrier's heads. When a tackler's head contacts the head or shoulder of the ball carrier, it's much more likely to result in a head injury assessment (HIA) compared to contact below the shoulder level. (Quarrie & Hopkins, 2008, p. 1712; Tucker et al., 2017a, p. 1152.) Several studies have indicated that tackles account for over half of all concussive injuries in rugby, making them the most common cause of these events. (Brown et al., 2019; Cross et al., 2017; Kaplan et.al, 2008, p. 90; Roberts et al., 2017; Starling et al., 2023; Tucker et al., 2017a.) Other factors that contribute to the risk of experiencing a concussion encompass various elements such as: past incidents of concussions, educational attainment, age, competitive level, behaviour, gender, unexpected physical contact, stiffness in the neck, psychological factors, strength of the neck, and the girth or size of the neck (Garnett et al., 2021, p. 2). Whiplash injuries are usually described to be originated from a severe hyperextension of the head followed by severe hyperflexion movement. Whiplash type injury is potentially facilitated by relatively weaker neck flexors compared to the neck extensors, indicated by a lower flexor/extensor strength ratio. (Nutt et al, 2022, p. 5.) A whiplash-type injury is suggested to be a prevalent mechanism of injury in women's concussions in rugby, particularly when a player being tackled hits their head on the ground. (Hall, 2022, Chapter 9: p. 37/48; World Rugby, 2023g.) Female ball carriers experience 45% of head impacts due to contact with the ground, while in contrast, for male player ball carriers had the highest likelihood of head injury from direct or indirect contact with another player (McLeod et al., 2023, p. 6). Women are exposed to a potential risk of sports-related concussions that could be as much as twice that experienced by men and female athletes typically need a longer recovery period following concussions in comparison to males (Alsalaheen et al., 2019, p. 779). There may be a need for more targeted injury prevention strategies for female rugby players (King et al., 2022, p. 1761; World Rugby, 2023g).

Concussion rates in rugby vary depending on the level of competition and the method of data collection. Recent statistics indicate varying injury rates, from 2 concussions per 1000 player hours at the community level to as high as 20 concussions per 1000 player hours in professional rugby. (King et al. 2022, p.

1756; Russell et al., 2022, p.1263; Williams et al., 2022, p. 1133.) The annual injury surveillance study for elite men's and women's international and domestic rugby reported an overall match concussion incidence rate in the men´s game of 14 concussions per 1000 player-match-hours and 10 concussions per 1000 player-match-hours for females (World Rugby, 2023f, pp. 8, 12). West et al. (2020, p. 4) investigated professional male rugby over 16 seasons between 2002 and 2019 which revealed that concussion incidence, severity and burden have all rose significantly over the years. Moreover, Russell et al. suggest that former international rugby players exhibit a higher mortality rate associated with neurodegenerative diseases compared to a matched, general population comparison group (Russell et al., 2022, p. 1266). Previously, the research on protective equipment's role in preventing sports-related concussions has been limited. However, recent findings are suggesting headgear do not prevent brain injuries in rugby. (Al Attar et al., 2024, p. 473; McCrory et al. 2017a, Chapter 20, p. 12/28; Schneider et al., 2017, p. 1).

Burners or stingers typically describe symptoms resulting from damage to the upper roots of the brachial plexus (C5–C6). This damage can occur from forceful compression or separation of the head from the shoulder, as might occur in a significant fall onto the shoulder or through excessive stretching. Stingers or burners are the one of the most prevalent acute nerve injuries among athletes, especially in high-contact sports like rugby. (Magee & Manske, 2021, p. 170; Tortora & Derrickson, 2007, p. 458; Warden, 2017, Chapter 3: p. 22/24.) Picture 5 demonstrates how the motion of the shoulder and arm combined with tilting the neck towards the opposite side can cause a traction injury, impacting either the brachial plexus or the cervical nerve root (usually C5/C6). Conversely, compression injuries may occur from a direct impact to the brachial plexus. (Jull & Falla, 2017, Chapter 23, p. 36/36.)



Picture 5. Mechanism of injury for brachial plexus (burner or stinger) pathology (Magee & Manske, 2021, p. 174)

6.1.2 Risk factors

According to World Rugby (2023b, p. 5) high risk athletes have a lowered tolerance for load and therefore need a focused management. They identify high-risk athletes as those falling within one or more of these categories: individuals engaged in multiple sports or teams, players coming back from injury, both young and veteran athletes, those transitioning to a higher competitive level for the first time, individuals with inadequate training backgrounds, and those burdened with substantial non-physical or life-related pressures. West et al. (2023, p. 1385) reports multiple relative risk factors (e.g. level of play, surface type, player weight, previous injury, previous concussion, use of regular weight training, position, match quarter, exposure type, season, match volume, history of shoulder dislocation and rugby itself versus other sport) acting as significant risk factors for injury occurrence in rugby. Swain et al. (2010, p. 387) verifies that considerable uncertainty remains around the tentatively identified risk factors discussed in the literature concerning rugby injuries. However, they acknowledge that research has progressed, leading to an increased understanding of these factors.

Specific game situations can be categorized as being a risk factors for injury in rugby. Most of the injuries in rugby are sustained during contact with another player, involving either the player being tackled or the one making the tackle (Brooks et al., 2005, p. 760; Kaplan et al., 2008, p. 88). Tackle-related risk factors include match quarter, awareness during tackling, initial contact point, the ball carriers fend, tackle speed and tackle type (Tucker et al, 2017b; West et al., 2023, p. 1385).

Factors contributing to the presentation of scrum-related injuries include the early deterioration of the cervical spine and discrepancies in size among front-row players, as well as the substantial impact forces involved. Additionally, components like the experience level of referees and coaches, scrum laws, technical readiness, suitable player selection, and tailored player conditioning are involved. (Brown et al., 2013.) More insights are essential to comprehend the correlation between mechanical forces within the scrum and injuries. Specifically, the documented shear forces raise concerns as a potential risk for the long-term deterioration of the spine due to unwelcome rotational and bending movements. Additionally, it is noted that the force exerted during the scrum engagement poses a specific injury risk, attributed to elevated compressive and shear loads, along with hyperflexion of the cervical spine. (Hamilton et al., 2014, pp. 1-5.) Appendix 2 evidence the risk factor findings by game situations for sustaining a head and neck injury in rugby. Furthermore, it shows how the study has predominantly concentrated on analysing the tackle event, rather than on scrums and other contact scenarios.

The relative risks factors of tackle heights have been confirmed in numerous studies. The technical skill level of a player has been recognized as significant injury risk factor and pivotal determinate affecting on performance. Video analyses specifically focused on head impacts and subsequent concussions have pinpointed tackling technique being a critical risk factor. Incorrect tackling technique significantly increases the risk of injuries, including the ones stemming from head-to-head contacts. (Burger et al., 2020, p. 7; Hendricks et al., 2023, p. 1; World Rugby, 2023g.) There are various other elements in addition to tackle height which elevate the risk of injury. Energy transfer during tackles overall poses a risk for head injuries, as factors like head placement, direction, type, and speed affect the likelihood of head injury assessments. By adjusting tackle height, leg drive, and tackle speed tackle performance technique can be altered. (Burger et al., 2017, p. 284; Edwards et al., 2021, p. 2; Tucker et al., 2023, p. 1152.) There seems to be a variance in the tackling technique depending on whether the player is tackling from their dominant or non-dominant side. In the non-dominant tackle, the tackler exhibits reduced control over head movement. (Seminati et al., 2017, p. 16.) Diminished proficiency in tackling technique has been linked to fatigue among players, consequently increasing the likelihood of unsafe tackles (Hendricks et al., 2016, p. 8). Finding the best tackle technique to use to minimize injury risk and improve performance for both the ball carrier and tackler remains elusive and despite the implementation of a new tackle rule, there's a continued rise in the occurrence of concussions among professional players (Chavarro, 2022, p. 86; Edwards et al., 2021, p. 2). Research continues to investigate the relationship between rugby techniques and injury risk as shown in appendix 2.

The player's position itself doesn't seem to be a contributing factor to sustaining an injury in RU. However, there is some variation, since there are increasing trends in the mean and median severities of match injuries sustained by forwards players that are statistically significant. (Fuller & Taylor, 2023; Fuller et al., 2020; Kaplan, 2008, p. 90; West et al., 2020 p. 2.) Possible reasons for the changes in injury severity and burden include the increasing mass and the speed of the players, and therefore the ability to generate greater energy in collisions (Quarrie et al., 2020; West et al. 2020, p. 4). There is a notably higher incidence of lower head acceleration events in forwards compared to backs, suggesting that the divergence in incidence is due to forwards participating in a greater number of contact events per hour than backs (Bussey et al. 2023b, p. 9; Tooby et al., 2023, p. 8). However, there's a distinct contrast between the propensity for head injury events in backline positions versus forward positions. The increased tendency for head injury events among backs likely stems from the specific tackle styles employed by the players. Specifically, factors like the speed and angle of the tackle, which have been proven to predict the risk of injury, might play crucial roles in this heightened risk for backline players. When both the ball carrier and tackler reach their peak speed, they experience the most intense inertial head movements and neck forces. Lighter players might face a comparatively lower risk because they're less often involved in tackling much heavier players. However, this reduced risk might be balanced by the fact that when they do tackle, it's typically against opponents moving at higher speeds. Furthermore, higher speeds may lead to increased disruptions in the visual field, thereby raising the complexity of locomotor tasks by introducing additional visual constraints. All these factors potentially explain, why there's a higher likelihood of head injuries among backline positions compared to forwards. (Brooks et al., 2005, p. 765; Tierney & Tucker, 2021, p. 303; Tucker et al., 2017b, p. 9; Zeff, 2023, p. 123.) Front row players experience a great amount of cervical spine trauma during scrummaging. Front row and lock players seem to experience more age-related changes in the cervical spine and at earlier age with greater severity than controls. It is hypothesized by that repetitive trauma may be linked to these findings. (Kaplan et al., 2008, p. 91; Scher, 1990, p 558.) The hooker position is linked to a notable incidence of permanent acute spinal cord injuries (Brown et al., 2013, p. 1).

Weakness of the muscles has not exactly been shown to act as a risk factor itself for sustaining injuries. However, the primary theory explains how sufficient neck strength safeguards against head and neck injuries since stronger and more rigid necks can stabilize the head during a collision. Neck stiffness refers to the degree to which the neck opposes deformation. (Elliott et al., 2021, p. 7.). Chavarro (2022, p. 260) highlights that it´s rather a matter of strength imbalances (namely flexion to extension ratios and bilateral flexion side ratios) which appear to be more linked with concussion injury incidence in RU than neck strength per se. Elliott et al. (2021, p. 7) highlights how the attention should be shifted from the pure neck muscle strength to the muscle fatigue, since that is how the relationship of the neck muscles to the risk of head and neck injury becomes more plausible.

Neuromuscular problems encompass issues with sequencing movements, delays in activating muscle responses, difficulties in adjusting postural muscle activity, and challenges in adapting motor responses to changing task conditions. Inadequate cervical proprioception poses a risk factor for concussions in RU. Diminished joint position sense, a prominent factor in rugby injuries, is characterized by reduced force production and less control over head movement during impacts, significantly contributing to head and neck injuries.

(Farley et al., 2022, p. 215; Shumway-Cook & Woollacott, 2012, p. 270.) Individuals experiencing neck pain experience alterations in the function of cervical and scapulothoracic muscles and specifically the activation of the deep cervical flexor muscles. These changes involve modified control methods and peripheral adaptations in cervical muscles, possibly resulting in reduced endurance, increased susceptibility to fatigue, diminished strength, altered proprioception, delay in neck muscle activation and reorganization of muscle coordination. Given the crucial role of deep cervical muscles in supporting the cervical spine, alterations in this feedforward response can potentially render the cervical spine more susceptible to reactive forces. (Comerford & Mottram, 2012, p. 219; Falla et al., 2004, Abstract; Jull et al. 2008, p. 531.) Reddy et al. (2022, p. 10) explain, how individuals with non-specific neck pain might experience reduced endurance due to increased pain intensity, triggering a reflexive inhibition of the muscles. Furthermore, this cycle of pain leading to weakness may occur as type 1 muscle fibers transform into type 2, consequently diminishing the capacity of their neck muscles. Salmon et al. (2018, p. 1078) discovered in their work that neck pain increased in both forwards and backs over rugby season indicating that rugby participation itself can have inconvenience effects on the neck.

Point in time affects the injury risk in rugby. Several studies suggest that injuries are more likely to occur in the second half of rugby game compared to the first half (Brooks et al., 2005, p. 763; Burger et al., 2017, p. 284; Hendricks et al., 2016, p. 8; Williams et al., 2013). Findings suggest that fatigue plays a role as a risk factor for injuries, yet pinpointing precise central or peripheral causes remains challenging (Brooks et al., 2005, p. 763; Hendricks et al., 2016, p. 8). There is some evidence to suggest that the time of the season may impact the incidence of injuries in rugby. The overall injury incidence rate has shown to be higher in the pre-season and early season compared to late season. (Bleakley et al., 2011; Brooks et al., 2005; Cross et al., 2016.)

Previous injuries and the risk of future injuries have a complex relationship which is particularly relevant in rugby due to the physical demands and nature of the game. Finch & Cook (2014, p. 1) underlines that during a single playing season, players may encounter various injuries, some of which may have no connection to prior incidents. However, it's not uncommon for subsequent injuries to be linked to previous ones. Williams et al. (2013, p. 10) state in their meta-analysis that new injuries in rugby occurs substantially more often than recurrent injuries. According to Moore et al. (2021, pp. 3-4), concussion stands out as the only injury that raises the risk of further injuries, increasing the risk by 26% post-concussion compared to pre-concussion. Additionally, concussions lead to a shorter duration before the occurrence of the next injury compared to injuries not related to concussions. Cross et al. (2016, p. 1) claim, that post a concussion, players are 60% more prone to experiencing any type of match-related injury compared to those who hadn't suffered a concussion. Moreover, players who return from a confirmed concussion have a shorter duration before encountering another injury compared to players returning from injuries other than concussions. Rafferty et al. (2017, pp. 969-973) state that there are several factors underlying behind the fact that concussion increases the occurrence of new incidents and not all of them are known. According to them, following concussion, specific body regions are at greater risk of injury including the head and neck, shoulder and arm, buttock and groin, and the lower limb (leg, ankle, and foot) areas. Tierney & Simms, (2017, p. 5) highlights that engaging repeatedly in high-impact tackles might lower the brain's ability to endure injury, reaching a stage where routine tackles become intolerable, and the buildup of micro damage could potentially result in lasting brain damage. Nutt et al. (2022, p. 1) estimated in their research that RU players with prior concussions had noticeable disparities in neck strength – especially in the lowered flexion/extension strength ratios. Gillies et al. (2022, p. 252) continue stating that players who demonstrated a lower flexor/extensor ratio had a significant history of head and neck injuries including SRC. Snodgrass et al. (2018, p. 1) highlights, that players which have sustained a neck injury previously or report neck pain during the season are shown to have diminished AROM values of the cervical spine, which in turn is contributing to the neck injury risk. Moore et al. (2021, p. 1) discovered that ankle ligament sprains were associated with a decreased risk of head, neck, and neurological injuries. They suggest that ankle rehabilitation including active rehabilitation, with objective evaluations and improvements in proprioception needs more investigation since they could potentially offer advantages for managing concussions.

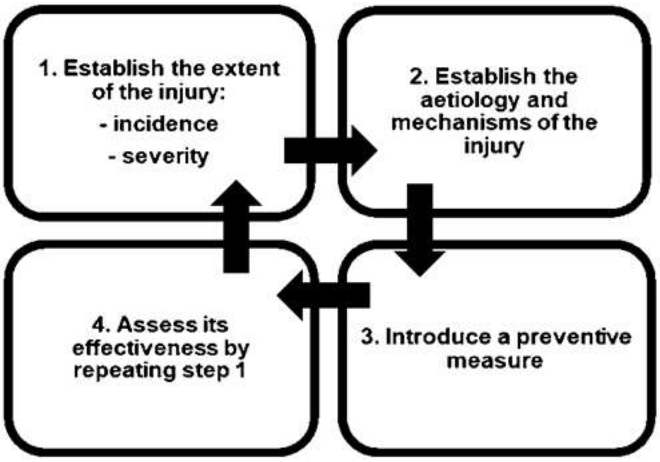
Foul play is a major risk factor for injury in rugby union since illicit or unfair acts which break the game's laws can result in severe injuries. Foul play is associated with 42% of concussions and a substantial number of fractures and dislocations. High and late tackles are identified as the most frequent foul play type, significantly escalating the risk of severe injury. (Bleakley & Tully, 2011, p. 561; MacAuley & Best, 2007, p. 100.)

Contextualizing the factors in terms of direct injury risk in rugby is a challenge since there is always the confounding or effect modification by other risk factors. It is essential to incorporate details about the mechanisms of injury and account the ways in which internal and external risk factors can alter the likelihood of injuries (Bahr & Krosshaug, 2005, p. 328). A coach's knowledge of the potential risk factors associated with sports injuries is vital since it empowers them to create a safer training and playing environment, educate their athletes about injury prevention, and identify and address potential injury risks early on. It is crucial to ensure that players practise and compete within safe thresholds suitable for their ages, abilities, and skill levels. Coaches should create training surroundings that improve players' ability to adapt and consistently participate in physical-technical competitions without raising their injury risks. Essentially, this aims to gradually prepare players for collisions and physical demands. (Jones & Kingston, 2013, p. 188; Paul et al., 2022, p. 31.) Risk factors for injuries in rugby are often influenced by cultural and social norms within the sport. A comprehensive understanding of these factors can help to develop targeted interventions to change behaviours and attitudes that contribute to injuries. This includes promoting safe play practices, discouraging risky behaviours, and fostering a culture of injury prevention. (World Rugby, 2023g.)

7 INJURY PREVENTION

Achieving success in performance and averting injuries relies on a properly structured and executed training regimen, proper nutrition, hydration, suitable physical and mental training, and adequate sleep & recovery. Several fundamental training principles apply universally to all sports, including periodization, overload, specificity, and individualization. Proper warm-ups and cool-downs are used for optimal performance and injury prevention. Strength and conditioning exercises can be incorporated to develop overall fitness and resilience. Inclusion of skill-specific drills aim enhancing technique and accuracy of the players. Regular rest periods in the training cycle can be considered to prevent overtraining and enable recovery. (Gabbett, 2016, p. 1; Hootman, 2007, Chapter 1, p. 14; O´Connell, 2020, p. 463; World Rugby, 2023e.) Preventing injuries in rugby involves often a multi-faceted approach that combines various strategies. These methods include, inter alia, policy and law changes, training, education, and protective equipment as well as elimination, substitution, and engineering of hazards. Furthermore, it is important to recognize injury prevention interventions as a fundamental component of normal daily training routine, rather than being a separate entity. (McIntosh & McCrory, 2005, p. 315; Pajari, 2019; West et al., 2023, p. 1389.) Usually, a combination of collective approaches of passive and active interventions are used in injury prevention in sports. Passive interventions, such as rules and regulations, are designed to have a broad impact as they relate to the whole aspect of the sport. Active interventions, such as education and training, are designed to empower players and coaches to adopt safer behaviors. Active participation enhances an individual's self-efficacy, a crucial factor influencing changes in actions. A combination of the two is considered to be the most effective. (Hendricks et al., 2023, p.2.)

Van Mechelen et al. (1992) introduced a conceptual model on sports injury prevention which is illustrated in picture 6. The model portrays how the first step is identifying and the describing the problem. Second factor is to identify the risk factors and injury mechanisms (understanding of the issue). The third phase is to introduce measures that are likely to reduce the future risk (based on aetiologic factors). Finally, all this should be evaluated by repeating the first step.



Picture 6. A conceptual model of injury causation by van Mechelen et al. 1992 (adapted from Bolling et al., 2018, p. 2229)

Exercise and prevention programs play a pivotal role in rugby by addressing various aspects of player health and performance. Prevention programs aim to minimize the likelihood of injuries, enhance overall fitness, accelerate recovery, prevent overtraining, cultivate mental resilience, educate players on injury prevention, and promote overall well-being. (World Rugby, 2023e.) Warm-up intervention programs including neuromuscular training, functional and proprioceptive exercises should be implemented as an integral part of injury prevention strategies. These programs have shown the potential to lower injury risks and significantly decrease injury rates. (Ding et al., 2022, p. 12; MacAuley & Best, 2007, Chapter 1, p. 14.) There are several exercise and prevention programs in rugby including New Zealand's “RugbySmart”, Australia's “SmartRugby”, South Africa's “BokSmart”, the International Rugby Board's (IRB) “Rugby Ready”, “Tackle Ready” & “Breakdown Ready” as well as World Rugby´s “Activate”. World Rugby (2023e) informs that Activate is a structured, progressive exercise programme designed to be used as part of training sessions and pre-match warm-up routines. It has been divided into four different parts including mobility, rolling, falling, and landing, deep neck stabilisation, neck strengthening and head reaction exercises. According to them the programme can reduce the number of injuries to muscles and ligaments (by 26-40%) and the number of concussions (by 29-60%) in youth and adult community-level rugby players. (World Rugby, 2023e.) Atwood et al. (2022, p. 506) state the necessity for players to adhere to the injury-prevention program at least three times per week for it to be effective as a real-world injury prevention measure. Different training interventions from World Rugby´s Tackle Ready injury prevention program are presented in appendix 3.

Load management is a structured approach that minimizes injury risks by carefully organizing and controlling the demands placed on an individual during life, training, and to a lesser extent, during matches. In recent years, increasing evidence has emerged to endorse load management as an effective strategy for preventing injuries. (World Rugby, 2023b, p. 3.) It has been speculated that high absolute training loads can heighten the risk of injury, prompting specific recommendations or regulations within certain sports regarding the overall volume of training and competitive participation athletes should undertake. Hence, evidence suggests that both over-training and undertraining can elevate the risk of injuries. (Gabbett, 2017, Chapter 12, p.26/42.) According to the World Rugby load management guideline, full contact load should be implemented maximum twice per week and the volume for high intensity contact should be limited to 15 minutes per week. Controlled contact should be no more than 40 minutes and live set piece contact training 30 minutes per week. (World Rugby, 2021j, pp. 3, 4, 7.)

There is evidence supporting the use of athlete education programs as a strategy to mitigate the risk of concussion in sports. (Daly et al., 2021, 4.7 Summary.) West et al. (2023, p. 1385) support educational approach stating that most promising results in the area of primary prevention in rugby have been produced from a compulsory educational training programme. Soomro et al. (2016, p. 2423) state, that although the precise mechanisms underlying the benefits of injury prevention programs are not fully understood, potential explanations suggest enhancements in muscular strength, proprioceptive balance, and flexibility, ultimately improving overall physical readiness for sports participation. Streifer et al. (2023) point out that some individuals could benefit from interventions targeting the cervical spine even before engaging in physical activities. According to them, it is essential to thoroughly assess the strength, girth, and posture of the cervical spine especially for athletes with a high risk. (Streifer et al., 2023, p. 206.)

Author claims, that effective injury intervention model can be complex to implement since there are various ways to put it into practice. Even the most scientifically proven, effective actions do not necessarily guarantee compliance, or translate into success in preventing injuries in the real-world context. However, by incorporating different injury prevention interventions into standard practice can not only benefit individual players but also lead to broader improvements in team performance.

7.1 Neuromuscular training

Neuromuscular training has shown efficacy in reducing sports injuries, with applications seen in the context of rugby (Eliason et al., 2023, p. 3; Hislop et al., 2017, p. 7; Hübscher et al., 2010, p. 1). In theory, enhancing the connection between the head, neck, and trunk by developing robust, rigid, and activated neck muscles is believed to help mitigate linear and rotational accelerations experienced during physical contact, especially when tackled. This is presumed to occur through a viscoelastic mechanism where the neck muscles function to dampen force and slow down head movements, preventing potential brain and neuron injuries. Improving neck strength, particularly in a more symmetrical manner, may contribute to increased stability in the head-neck segment, lowering transmitted forces and potentially reducing the risk of head and neck injuries, including sports-related concussions. (Gillies et al., 2022, p. 252.) Strength symmetry in agonist-antagonist muscle pairs plays a crucial role in injury prevention across various sports. It has been hypothesized that maintaining balanced strength between opposing muscle groups ensures proper joint function, movement control, and neuromuscular coordination, which could reduce the risk of injuries. Isometric tests reveal that the strength of cervical extension is typically higher than that of flexion. Nonetheless, there is a suggestion that when the production of extension and flexion strength (i.e. flexion/extension -ratio) are equal, it may provide greater protection for the head and neck during impacts. (Chavarro-Nieto, 2022, p. 8; Streifer et al., 2023, p. 203.)

In various sports, strong physical attributes are linked to a decreased risk of injury. While neuromuscular training is a valuable component of injury prevention in rugby union, identifying the ultimate best strategies is a complex endeavour due to the diversity of injuries, individual variability, limited research, and the evolving nature of the sport. The author has compiled multiple perspectives, findings and suggestions related to physical aspects in injury prevention from different literature sources to table 5.

Table 5. Injury prevention strategies regarding neuromuscular training – findings from the literature

Topic	Comment	Reference
	Neck strength, girth, and cervical spine posture have been identified as potential factors that may reduce SRC risk by decreasing linear and rotational head acceleration and the magnitude of force upon impact.	Streifer et al., 2023, p. 204
	There is clinical worthwhile evidence to support the inclusion of neck exercises into injury reduction exercise programs to reduce the incidence of sport-related head and neck injuries including concussion	Elliott et al., 2021, p. 1
	Considering the relationship between lumbar spine position and its influence on the cervical spine, it has been proposed that control of the lumbar spine may also influence positioning of the head, neck, and shoulder during contact activities such as tackling	Low et al., 2023, p. 99
	The ability to withstand forces indirectly or directly applied to the head has been proposed as a possible mechanism to reduce traumatic brain injury and concussion.	Garnett et al. 2021, p. 2
Neuromuscular	Players with stronger necks in flexion and extension had a significant reduction in medial and lateral angular and linear head accelerations. The pre activation of the neck flexor and extensor muscles before a collision has been shown to significantly decrease the peak linear velocity and de accelerating of the head.	Chavarro-Nieto et al., 2021, p. 16
	Greater neck strength has been associated with lower risk of head and neck injury, including concussion in athletes.	Attwood et al., 2022, p. 506
	Properties such as muscle strength, muscle mass and the timing of muscle activation have all been shown to attenuate the force and resultant head movement	Reha et al., 2021, p. 2
	Activating the neck and posterior shoulder muscles reduces the risk of concussion by mobilizing the head, thereby decreasing the resultant acceleration of impact to the head.	Hendricks et.al, 2016, p. 8
	Greater neck strength alone is unlikely to reduce the risk of SRC without proper neuromuscular control and a high rate of force development	Garrett et al., 2023, p. 14
	Training safe and effective tackle and ball-carrying techniques under both nonfatigued and fatigued conditions, and instituting rugby fitness and conditioning that aim to better prepare players for real-match situations may be necessary to counter the negative effects of fatigue on tackle and ball-carrying proficiency.	Burger et al., 2017, p. 284

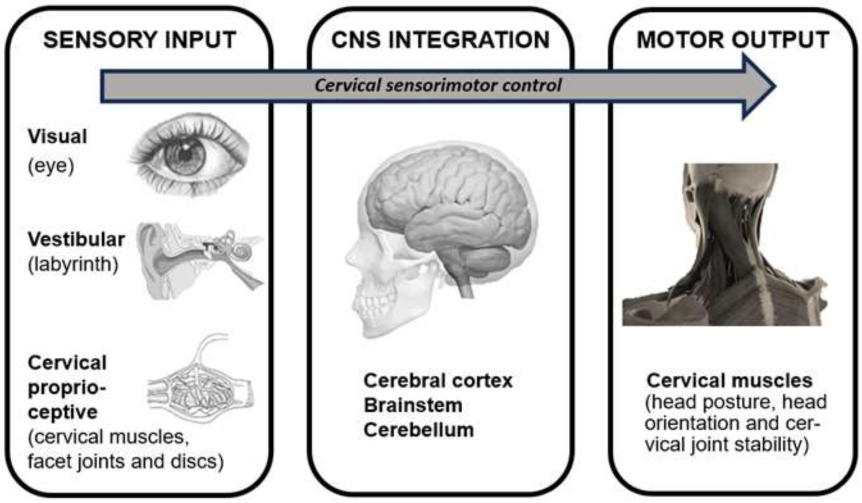
	Participation in on-field neuromuscular training (NMT) warm-up programmes completed at least three times per week has been associated with a lower rate of concussion in RU across all age groups.	Patricios et al., 2022, p. 699
	There is level 1A evidence that neuromuscular, functional, or proprioception exercise programs and prophylactic equipment are effective in reducing sports injuries.	MacAuley & Best 2007, Chapter 1, p. 14
	Some evidence supports up to 60% lower concussion rates with implementation of a neuromuscular training warm-up programme in rugby.	Eliason et al., 2023, p. 3
	Completing the intervention programme 3 times per week led to substantial reductions of 72% in overall match injury incidence and 72% in contact-related injury incidence compared with the control programme (youth rugby).	Hislop et al., 2017, p. 7
	Anticipation and preloading influence dynamic head stability. Preloading stiffens the neck, allowing for greater energy absorption during impact.	Alsalaheen et al., 2019, p. 779

Daly et al. (2021, p. 12) concur there is still insufficient research to definitively establish the effectiveness of neuromuscular interventions in reducing cervical spine injuries and concussions. Similarly, Chavarro (2022, pp. 270, 85-86) identifies a gap in the literature concerning the proprioceptive impact of neck strengthening exercises and the overall value of proprioceptive or neuromuscular exercises in preventing neck and concussion injuries. He proposes future research in rugby focusing on implementing neuromuscular, eccentric, and anticipation-for-impact training to assess the relevance and effectiveness in the context of reducing concussions in rugby.

7.1.1 Movement control of the neck

The proprioceptive system in the cervical spine is highly sensitive and plays a pivotal role in regulating posture and balance. The anatomical connections among the cervical spine, temporomandibular joint, thorax, and shoulder girdle, along with the musculoskeletal and neurovascular structures, contribute to the complexity of movement control function of the cervical spine. The afferent-efferent network of neuromuscular reflexes integrates with the vertical spine, establishing rich reflex connections with the auditory, visual, and vestibular apparatus. The precise control and discrete function of the neuromuscular system endow muscles with a shock absorption function. Receptors in neck muscles include muscle spindles, Golgi tendon organs, pacinian corpuscles, and free nerve endings which play a crucial role in supplying the central nervous system with detailed information about head position and movement. This sensory information is then utilized to assist in controlling head movement by adjusting subsequent descending neural signals forming the proprioceptive system. (Comeford & Mottram, 2012, p. 219; Conley et al., 1997, p. 2109; Portfield & DeRosa, 1995, p. 12-13.)

The visual, vestibular, proprioceptive, and muscle endurance systems work together in a complex interplay to maintain functional joint stability, balance, and coordination. Coordination provides the performer with the adaptability to respond to sudden changes in the task, environment, or their own body. The dynamic stabilization of the head primarily relies on the cervical musculature's ability to absorb loads when faced with perturbations. (Jones et al., 2013, p. 157; Reddy et al. 2022, p. 1; Reha et al., 2021, p. 2.) Farley et al. (2022, p. 215) conclude that proprioception plays a vital role in aligning the head and neck with the torso. Achieving optimal alignment of these areas enhances efficiency in absorbing the force of an impact and correctly operating proprioception in the cervical musculature plays a crucial role in reducing force impact during rugby collisions. Picture 7 provides a visual representation of the complex interplay governing motor control.



Picture 7. Schematic diagram of cervical sensorimotor control (adapted from Peng et al., 2021, p. 145)

Rugby players can have compromised proprioception of the cervical area. Lark and McCarthy (2007, p. 890) found in their research that rugby players exhibited a diminished capacity to return to a neutral position after neck extension when compared to non-rugby players. According to Bussey et al. (2023, p. 14), concussion injuries are linked to notable deficits in cervical spinal motor control among male rugby players. Additionally, Gabbett (2017, Chapter 12, p. 26/42) emphasizes that overloaded athletes may experience impaired neuromuscular control, reaction time, and decision-making ability. Zeff (2023, p. 123) reports, that athletes in contact sports adjust their motion patterns differently in response to changes in speed and visual tasks compared to athletes in non-contact sports. Streifer et al. (2023) remind that head posture itself is a significant matter influencing on neck muscle functions. According to them, forward head posture heightens the activation of the sternocleidomastoid and upper trapezius muscles, leading to subsequent inhibition of the deep muscles responsible for segmental stability and neck proprioception. Furthermore, forward head posture has been shown to correlate with diminished flexion-extension strength ratio (Streifer et al., 2023, p. 203).

Evidence from studies endorses the efficacy of exercises that target various facets of sensorimotor function, with a particular emphasis on enhancing cervical proprioception and muscle coordination (Peng et al., 2021, p. 144). According to Kraemer et al. (2021, Chapter 5), contemporary exercise programs are incorporating new training methods to enhance the bidirectional communication between muscles and the central nervous system. Effectively training these neuromuscular pathways is anticipated to increase resistance to fatigue, thereby sustaining optimal performance in complex athletic movements for an extended duration during competitions and training sessions.

Jull & Falla (2017, Chapter 23, p. 30/35) emphasize the importance of addressing any altered coordination between the deep and superficial cervical muscles or diminished endurance capacity of the deep neck flexors with athletes. Often, it is necessary to first learn the correct movement of craniocervical flexion and once the proper movement is mastered, training can then be directed towards improving the endurance of the deeper cervical flexors. Moreover, according to Jull et al. (2009, p. 701), in cases where the synchronization between the superficial and deep flexors is not accurate, the functioning of the superficial muscles could potentially overshadow or compensate for any compromised activity of the deep cervical flexor muscles during more strenuous exercises. Atwood et al. (2018, p. 7) assert that there is evidence of effectiveness of a movement control injury prevention program which has been demonstrated with clear beneficial effects in adult men's community rugby players.

7.1.2 Strength

Increased neck strength can reduce the magnitude of head movements during collision events in rugby and thereby also decreases the likelihood brain injuries. A stronger neck is correlated with decreased head velocity, peak acceleration, and displacement during impacts. Resistance training enhances muscle activation, causing capacity to engage motor units of high twitch forces and rapid twitch times. This enables rapid force generation to minimize head and cervical displacement and this ability could potentially mitigate or lessen the severity of injuries. An increasing body of evidence suggests that integrating neck-strengthening exercises into warm-up routines or strength and conditioning sessions has been linked to a reduction in head and neck injuries in rugby. (Attwood et al., 2022, p. 506; Atwood, 2018, p. 6; Chavarro, 2022, p. 86, 88; Conley et al., 1997, p. 2110; Doran & Naidoo, 2021, p. 6; Garnett et al., 2021, p. 12; Streifer et al., 2023, p. 203).

Isometric and eccentric exercise is commonly employed as a strategy for injury prevention among both professional and amateur athletes. However, isometric neck strength may not suffice to decrease the occurrence and se-verity of head injuries. Eccentric training induces more significant alterations compared to concentric training. It reduces contraction time, enhances radial displacement velocity, and influences muscle belly displacement, potentially making it a more effective training method. (Ansari et al., 2023, p. 306; Chavarro-Nieto et al. 2021, p. 16; Burgess, 2017, Chapter 10, pp. 8-12; Burgos et al., 2023, p. 4; Pakosz et al. 2023, p. 1; Roig et al., 2008, p. 556.) In general, the neck's extensor muscles force is considered to be the strongest, followed by the lateral flexors, while the flexors are comparatively weaker. This characteristic is particularly evident among forward players who often exhibit neck extensor dominance. (Gillies et al., 2022, p. 252.) Enhancing the endurance capacity of both the deep cervical flexors and extensors could play a significant role in injury preventions perspective. Proper activation of both of these muscle groups is believed to reduce reliance on superficial muscles for more controlled movement of the cervical spine. (Streifer et al., 2023, pp. 203-205.) The literature widely supports the recruitment of deep neck flexors when incorporating neck stabilization (Chavarro-Nieto et al. 2021, p. 17).

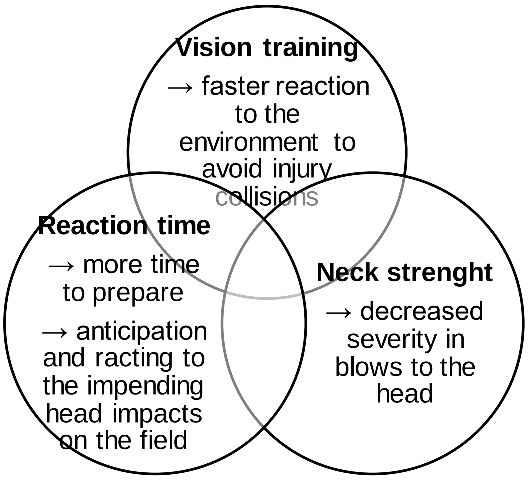
Males and females may employ different approaches to stabilize the head. Women rely more on neuromuscular activation to achieve similar levels of head angular velocity and neck extension excursion as men. Although greater neuromuscular activation in women may effectively stabilize the head during loads, it might not be as effective in mitigating repeated head impacts sustained during rugby events since increased neuromuscular activation could lead to faster fatigue, potentially explaining the higher risk of concussion among female athletes. (Alsalaheen et al., 2019, pp.783-784; Williams, E. et al., 2022, p. 1655.) Studies investigating neck strengthening interventions to reduce cervical injuries and concussions remain limited, and identifying the most effective strengthening programs for different playing levels remain indecisive (Chavarro-Nieto et al., 2021, p. 2; Daly et al. 2021, Practical Applications).

7.1.3 Reaction & vision training

Reducing the risk of SRC may not rely solely on neck strength. Other essential factors include effective neuromuscular control, rapid force development, and proper head control. Neuromuscular control ensures that the relevant muscles contract quickly, aiding in head stabilization. (Elliott et al., 2021, p. 7; Garrett et al., 2023, p. 16.) Honda et al. (2018) assert that, only reaction time has garnered consensus as a measure to help prevent concussions. According to their findings, a quicker reaction time enables athletes to better shield their heads from severe impacts. Additionally, a fast reaction time allows athletes to anticipate an incoming hit, providing them with more time to brace and prepare their bodies and heads for the impact. This proactive approach is believed to reduce the severity of impact and the resultant forces on the head. (Honda et al., 2018, p. 710.) Hendricks et al. (2016, p. 8) emphasize that a player has the potential to endure significantly greater forces without sustaining injury when the cervical muscles are tensed and that the tensing of muscles occurs when an athlete anticipates an impending collision. Eckner et al. (2014, p. 9) similarly propose that adopting a "bracing for impact" approach can be an effective strategy in diminishing the risk of concussion related to sports collisions.

Significant evidence suggests that the anticipatory activation of cervical muscles operates independently of neck strength. Additionally, it is the velocity of neck muscle contraction, rather than muscle strength alone, that reduces the impact force, contributing to further attenuation of head kinematics in response to loading. The tension developed before a collision has the potential to decrease the linear and rotational acceleration of the head and thereby reduce the risk of sports-related concussions. (Eckner et al., 2014 p. 11; Elliott et al., 2021, p. 8; Farley et al., 2022, p. 215.) Actually, Reha et al. (2021, pp. 2, 6) argue that neck strength would have little impact on reducing head acceleration and alterations in neck strength do not affect head velocity during head impacts. According to them the timing of neck-muscle activation before an impact would hold more significance than neck muscle strength per se.

Visual training has the potential to reduce sport related concussions. It is a specialized form of training that aims to enhance the visual system's ability to process information and react quickly. It is becoming increasingly recognized as an important component of injury prevention in various sports, including rugby. The visual system plays a crucial role in rugby performance, as it provides the information needed for athletes to make split-second decisions, coordinate movements, and maintain balance. Vision training has the potential to enhance overall athletic performance, improve in eye-hand coordination, reaction times, and peripheral awareness on the field of play. Furthermore, vision training programs may contribute to a decrease in concussion rates. (Clark et al., 2020, p. 8; McCrory et al., 2017b, p. 8.) Visual skills include visual acuity, depth perception, fusion flexibility, contrast sensitivity, eye tracking, hand-eye coordination, eye focusing, peripheral vision, speed recognition, visual response time, and visual memory (Millard et al., 2023, p. 46). Moore et al. (2021, p. 4) state, that since the ensuing injuries in rugby involve the head/neck and have neurological implications, rehabilitation should focus on addressing disruptions to the vestibular-ocular system, postural control, and the ability to perform dual tasks with visual stimuli. According to them, these aspects are important, as they may adversely affect decision-making and skill execution in the context of rugby. Hendricks et al. (2016, p. 10) assert that incorporating training interventions specifically designed to enhance peripheral vision is a critical element in targeted training programs when the aim is to promote safe and effective play with the overarching goal of reducing the risk of concussion. As per Honda et al. (2018, p. 711), in picture 8 illustrate, potential factors to prevent concussive events include vision training, neck musculature strength, and reaction time training.



Picture 8. Potential factors to prevent concussions (Honda et al., 2018, p. 710)

7.2 Technique

Several studies have explored the potential role of proper technique and form in reducing the risk of injury in rugby players (Suzuki et al., 2021; Tucker et al., 2017a; van Tonder et al., 2023b). Van Tonder et al. (2023a, p. 60) pinpoint that the tackle event is a focal point for intervention, presenting an opportunity to mitigate injury risks to players. Brooks et al. (2005, p. 765) are reasoning, that the tackle situation is less predictable since it is executed in open play situations compared to activities like scrummaging and mauling, which primarily involve closed skills. Burger et al. (2020, pp. 7, 8) propose that evidence-based education and progressive tackle technique training are key modifiers in enhancing players tackle actions and technical abilities. Dane et al. (2022, p. 7) argue, that different playing positions exhibit distinct requirements for movement and physical contact, and these factors should be considered by professionals when devising training regimens.

There are several suggestions related to technical performance in order to mitigate the injury risk in different rugby situations. To ensure both effectiveness and safety in tackling, it is recommended to maintain a low body position or transition from an upright stance to a lower one before making contact. It is advised that when tacklers perform dominant tackles, they should aim to contact the ball carrier around the midsection rather than the hips since tackles aimed at the lower body seem to decrease the inertial loading on the head and neck of the ball carrier. In smother tackles the tackler's engagement to contact with the ball carrier should be adjusted accordingly. Crucially, the tackler should always position their head outside the ball carrier when making contact. (Edwards et al., 2022, p. 1568; Hendricks et al., 2023, p. 1; Tierney & Simms, 2017b, p. 16.) To lower the risk of Head Injury Assessment (HIA) for tacklers, the findings indicate that aiming below the upper trunk for upper body tackles is advisable while in lower body tackles avoiding the upper legs is recommended. Furthermore, active feet during tackling and correct head positioning can be recognized as effective strategies for preventing concussions. (Tierney & Simms, 2017a, p. 4; Tierney & Simms, 2018, p.11.) Physical fatigue has the potential to impact players' tackling technique. There is a relationship between particular physical attributes and specific techniques revealing how physical traits contribute to enhancing tackling performance. (den Hollander et al., 2023, pp. 11-15; Paul et al., 2022, p. 34-35.)

It is important to address the inherent risks associated with rugby techniques. The fact that many of the most effective game techniques in rugby are often also the most dangerous constitutes a significant limitation in injury preventions perspective. This intricate balance of factors should be taken into consideration in interventions focused on educating techniques. The practical challenges stem from evidence suggesting that front-on shoulder tackles and tackles with leg drive are the most effective for success. However, the optimal technique for achieving peak performance may conflict with the one for minimizing the risk of head injury, as front-on tackles and tackles involving acceleration and speed are more hazardous. While certain techniques may mitigate risk in one aspect, they may heighten it in another. For example, changing the tackle height might escalate the risk of specific injuries to the tackler, even if it diminishes the risk of head injuries for the ball carrier. (Tucker et al., 2017, p. 1156.) Determining the definitive best tackling technique in rugby can be a complex matter, since the optimal approach varies depending on the specific situation, the individual player's characteristics, and the nature of the game. Effective tackling requires a combination of physical technique, decision-making, and adaptability, all of which are honed through experience and coaching. However, some universal principles in injury preventions perspective apply to the tackle situation as illustrated in table 6.

Table 6. Tackling & ball-carrying techniques associated with injury prevention (adapted from den Hollander et al. 2020, pp. 9, 10)

Role	Pre-contact	Contact	Post contact
Tackler	→ Identify ball carrier onto shoulder → Body position -upright to low (dipping) → Back straight, centre of gravity ahead of support base → Alignment square to ball carrier → Head up and face forward → Boxer stance -elbows low and close, hands up → Shortening steps → Approach from front/oblique	→ Contact with shoulder → Contact in centre of gravity → Head placement in correct side of ball-carrier	→ Shoulder drive upon first contact → Leg drive upon contact → Punch arms forward, wrap and pull (hit and stick) → Release ball-carrier and compete for possession
Ball carrier	→ Focus on tackler → Body position – upright to low (dipping) → Back straight, centre of gravity ahead of support base → Head up, face forward	→ Fend into contact → Side-on into contact → Explosiveness on contact → Body position – from low up into contact	→ Use of arm and/or shoulder to push tackler → Leg drive upon contact → Grounding - chin tuck, arms close body and ball presentation

8 CONCLUSIONS

Rugby involves intense physical contact, tackling, and collisions resulting in relatively high injury risk, especially if comparing to non-contact sports. Injury prevention in the head and cervical area in rugby context presents unique anatomical challenges such as biomechanical complexity, limited protection, vulnerability to trauma and risk of neurological damage.

Injuries in rugby often result from a combination of factors and their effectiveness in preventing injuries may depend on how they interact with each other. Complexity of injuries, dynamic nature of the sport and the variety between players' skills, physical fitness, and experience makes it difficult to develop targeted prevention protocols which would adequately cater to these individual differences. Therefore, a common consensus on effective injury prevention training protocols seems to remain elusive. However, equipping players, coaches, and referees with a deep understanding of head and neck injury mechanisms, risk factors, and prevention strategies is paramount. This includes recognizing dangerous techniques, understanding concussion protocols, fostering a culture of player safety and adequate preparation for the game. The author has synthesized encompassing key findings from this report into table 7.

Table 7. Key findings − summary of theory and research on head and neck injuries in Rugby Union

Key findings:

- Rugby injuries can be classified into extrinsic or intrinsic; acute or chronic. Several distinct external and internal risk factors influence to the probability of injury. Risk factors are either modifiable or non-modifiable.
- The overall match injury incidence is higher in men´s game. The most common injury types are joint, muscle and tendon injuries. Concussion is one of the most common specific injury. The higher level of play rises the likelihood of injuries.
- Acute head and neck injuries include muscle strain and sprains, vertebral fractures, spinal cord damages, burners and stingers, cervical disc pathologies, lacerations, head acceleration events, concussions, and whiplash injuries.
- Biomechanical complexity, limited protection, vulnerability to trauma, sex differences and risk of neurological damage play a significant anatomical challenge in injury prevention of the head and neck area.
- Imbalances in neck musculature are a potential risk factor for neck injuries, where flexion-to-extension ratio imbalances have been associated with higher head angular and linear accelerations.
- Head acceleration injuries are a serious risk for both male and female rugby players. Rotational motion causing shear deformation is the main mechanism of concussion injury.
- Individuals experiencing neck pain can experience alterations in the function of cervical muscles. Changes involve modified control methods and peripheral adaptations such as reduced endurance, fatigue, diminished strength, altered proprioception, reorganization of muscle coordination & muscle fiber type.
- The tackle should be the priority area focus injury prevention efforts.
- Research on analyzing injury patterns or training strategies of rugby athletes in Finland regardless of gender, are currently limited. For female players globally, this deficiency is even more pronounced.
- Neuromuscular, functional, and proprioception exercise programs targeting on strength, conditioning, spatial awareness, reaction time and anticipation as well as emphasizing safe and effective playing techniques are an essential component of all-encompassing rugby training.

There is conflicting and limited evidence of the effectiveness of strength training when considering head injuries. Currently, there exists a significant side of research concentrating on head accelerations, rotational forces, and impact assessment to the head. However, at present, these approaches do not provide yet sufficient knowledge or practical tools when considering reducing the incidence of concussions. Hence, the type and amount of best possible training interventions remain uncertain. However, implementing targeted neck strengthening exercises as part of regular training programs can significantly enhance neck muscle resilience and potentially reduce the risk and severity of injuries.

9 IMPLEMENTATION

This thesis explored the development and implementation of a targeted workshop for the Finnish national team. The whole thesis process lasted approximately one year. During the first phase a comprehensive literature review was conducted, analyzing existing research on injury mechanisms, risk factors, and current prevention protocols. Theoretical background reviewed and identified specific knowledge gaps and areas for potential improvement.

Leveraging the research findings, a workshop was designed, tailored to the specific needs and knowledge level of the national team. The summarizing of the message stood as a pivotal aspect of the presentation since it was impossible to present all the data. The author decided to focus on modifiable risk factors such as physical conditioning and training strategies. The content and the delivery style of the workshop were tailored to the players' and staff's specific needs and knowledge level, considering their experience and background. The workshop incorporated a PowerPoint presentation and practical demonstrations, addressing some testing and evidence-based prevention techniques. As Suurmunne (2013) explains, a good visual presentation is a successful combination of text and image: loose, clear and proceeds logically. It should visualize key points, evoke emotions, and complement the contents of the presentation. The speaker's gestures and other body language contribute the message. The presenter's role as a rouser of enthusiasm and trust is important. (Suurmunne, 2013, p. 10.)

The workshop was delivered to the Finnish national team in March 2024, fostering dialogue and promoting player safety awareness. The event lasted approximately 1.5 hours and was attended by 26 players in addition to few team personnel. The workshop used clear explanations to spark discussions and questions. Active listening and engaging activities aimed addressing individual needs effectively. Suurmunne (2013, p. 5) explains, how a carefully organized presentation enhances comprehension and ignites enthusiasm among participants as part of the solution. Additionally, it addresses questions and concerns even before they arise. The working phases and tentative time management with the presentation are listed in table 8.

Table 8. Time estimation for building an hour-long presentation (adapted from Duarte 2008, p. 13)

Hours	Working phase
6-20	Research, gathering data
1	Charting the clients needs
2	Ideas of creating the message and documentation
1	Organizing the ideas
1	Feedback from the colleagues
2	Drafting the structure/storyboard
20-60	Producing the content with the application
3	Practicing the presentation
36-90	All

Post-workshop evaluation was conducted through participant survey. The collected data assessed the workshop's impact on knowledge acquisition, attitudes, and perceived preparedness for preventing head and neck injuries. The survey revealed that all the participants (26/26) agreed that the topic of injury prevention is important in rugby. Majority of the participants (24/26, 92%) reflected gaining new information about head and neck injuries. 27% (7/26) revealed considering their physical preparation has not been at sufficient level in order of preventing head and neck injuries in rugby. Furthermore, open written feedback unveiled that some of the participants might do some changes to their exercise routine in the future. Implementation of the workshop highlighted the value of research-informed strategies and expert collaboration in optimizing educational interventions for athletes. The event contributed to the ongoing effort to enhance player safety and well-being within the sport of rugby union in Finland.

The validity of the work was assured by aligning the presentation with the best available current scientific evidence and best practices for head and neck injury prevention in rugby. The study was conducted in accordance with the ethical principles provided by The Rectors’ Conference of Finnish Universities of Applied Sciences ARENE. Honest, responsible, and correct operating methods have been used in conducting the research. The sources are reliable, the sources have been cited appropriately, the research material and process are well documented and the result in the work is reliably stated. Informed consent was obtained from all participants in the event. Participation was voluntary, and participants were free to withdraw at any time without penalty. Feedback was stored securely and de-identified to protect participant privacy. All participants were provided with information about the project and were given the opportunity to ask questions and were encouraged to discuss about the work. Participants to the event were recruited from SRL national teams. The potential for participants to experience emotional distress from discussing their experiences of head and neck injury was noted. This risk was minimized by providing participants with support and debriefing opportunity after the event.

The accessibility of this document has been guaranteed by using ready thesis-template provided by Satakunta University of Applied Sciences. In the formatting of this report built-in Word styles has been used to mark structures. English was used as document language in document settings. The accessibility of this document was inspected using MS Word's Check Accessibility function after which the final changes to the contrast of the tables were made. Finally, the original Word file was converted into PDF/A file before uploading it to the Theseus database. This publication is available in Theseus and can be found at https://publications.theseus.fi The supplementary outcome (PPT file) referred in objective and implementation are available to the public in SRL´s website.

10 DISCUSSION

The author claims that the topic of the work is very relevant to this time. Head and neck injuries are a significant concern in rugby and prominent efforts have been made to confront this issue. Author claims that addressing athletes' well-being requires a multifaceted approach, including comprehensive education, the knowledge and the initialization of improved training methods and better resources to ensure their safety and longevity in the sport. Successfully implementing injury prevention strategies is a complex task, and much depends on the motivation and knowledge of the staff involved. This is perhaps more evident in Finland where the game has limited popularity and resources.

The workshop provided a divergent approach method distinct from traditional training interventions. Workshop covered all relevant aspects of head and neck injury prevention, including risk factors, mechanisms of injury and preventive strategies (e.g. tackling technique and physical preparation). However, return-to-play protocols were not addressed since the work was limited to primary prevention strategies. The chosen approach allowed not only to address the primary research question but also to organize the evidence in a format beneficial for key stakeholders. The content strived to consider the specific needs and concerns of Finnish rugby players and coaches, for example, the challenges arising from the limited amount of access to quality playing and training environments as well as participation commitment was addressed and discussed. The tailored activities performed during the workshop were appropriate for the target group and conducive to learning. Furthermore, the athletes gained some knowledge about their own performance level and got ideas how to address the possible weaknesses. Encouraging of athletes to understand the injury risks adopt preventive measures as like proper warm-ups, techniques and rest was a part of the content of the workshop. By actively managing these aspects, rugby players have the potential to maximize their physical preparation and mental resilience, ultimately enhancing their performance on the field. Long-term impact requires sustained efforts beyond the workshop.

While collecting, synthesizing, and analyzing data for the thesis, the author encountered some challenges. Establishing the scope and boundaries of the content proved to be difficult. Accessing, reading, organizing, and thoroughly analyzing the data required a significant amount of time and effort. Additionally, synthesizing and structuring the content presented a daunting task that had to be tackled incrementally. The author, who had never undertaken a project of this scale before, sometimes felt isolated despite peer support. Undoubtedly, producing this type of thesis also assesses and validates the student's capacity for independent work. The author felt having enough knowledge and experience to deliver the workshop effectively and felt having adequate familiarity with current research and best practices in head and neck injury prevention. Still, the author could not help feeling a slight frustration, since she was not able to give any straight answers or “easy fixes” due to the complex nature of the topic. However, this perspective may not align with the views of many participants, as the feedback was generally well-valued.

One of the objectives of this work was to consolidate existing research on physical conditioning strategies aimed at addressing specific modifiable risk factors in the prevention of head and neck injuries in rugby and share this information with the stakeholders. This aim was reached as the feedback questionnaire revealed. The strength of the workshop event was undoubtedly its provision of information aimed at enhancing awareness, fostering reciprocity through the sharing of experiences as well as the value from the practical part. Applying this knowledge to rugby training design is vital because it's crucial to explore training methods that improve contact readiness without increasing the risk of head acceleration events. Hopefully, the current and future research gives more answers to this query. Possible specific key learning outcomes and the effects on the implemented training regimens and effect on injury prevention of the participants of the workshop as well as rugby players of Finland remains unrevealed, and this aspect would need further research. It would be an intriguing topic to explore what possibilities virtual reality-based interventions provide when considering reactions and decision-making abilities in rugby scheme. Another interesting aspect of research would be the female athletes training and playing characteristics in Finland.

A potential limitation of this work is that the majority of the Finnish rugby scene wasn't able to participate in the workshop. This limited reach could hinder the spread of the message unless the workshop is offered again, or whether participants actively share their knowledge acquisition with others. A minor limitation of the workshop was that there was no time to delve deep enough into the complex topic or go through many of the technical issues of the performance. Follow-up sessions and specific training would be needed for more comprehensive application. The author acknowledges that raising awareness and knowledge is essential, but changing potential ingrained behaviors and habits can be challenging. Coaches, trainers, and athletes who lead by example play a crucial role in injury prevention in this scheme. Furthermore, author claims, that being rugby ready requires dedication, discipline, and a proactive approach to self-improvement.

Rugby is a continuously evolving sport, with rules, equipment, and playing styles changing over time. The inherent physicality of the sport itself predicates that injuries remain an inevitable part of the game. However, the author is convinced that through concerted efforts to mitigate injury risks, rugby can continue to be a physically demanding and captivating sport without compromising athletes´ well-being.

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APPENDIX 1: MUSCLE TABLE

Muscles information according to Netter (2019) & Tortora & Derricson (2017)

Posterior superficial muscles	Origin & Insertion	Action	Innervation
Semispinalis capitis	O: Articular processes of C4–C6 and transverse processes of C7–T7. I: Occipital bone between superior and inferior nuchal lines.	Acting together, extend head and vertebral column; acting singly, rotate head to side opposite contracting muscle.	Cervical spinal nerves.
Spinalis capitis	O: Often absent or very small; arises with semispinalis capitis. I: Occipital bone.	Extends head and vertebral column.	Cervical spinal nerves.
Splenius capitis	O: Ligamentum nuchae and spinous processes of C7–T4. I: Occipital bone and mastoid process of temporal bone.	Extend head; acting together, muscle of each region (cervical and thoracic) extends vertebral column of their respective regions.	Cervical spinal nerves.
Sternocleidomastoid	O: Sternal head: manubrium of sternum; clavicular head: medial third of clavicle. I: Mastoid process of temporal bone and lateral half of superior nuchal line of occipital bone.	Acting together (bilaterally), flex cervical portion of vertebral column, extend head at atlanto-occipital joints; acting singly (unilaterally), laterally flex neck and head to same side and rotate head to side opposite contracting muscle. Laterally rotate and flex head to opposite side of contracting muscle. Posterior fibers of muscle can assist in extension of head.	Accessory (XI) nerve, C2, and C3.
Levator scapulae	O: Transverse processes of C1–C4. I: Superior vertebral border of scapula.	Elevates scapula and rotates it downward.	Dorsal scapular nerve, cervical spinal nerve C3–C5.
Rhomboid minor	O: Spines of C7–T1. I: Vertebral border of scapula superior to spine.	Elevates and adducts scapula and rotates it downward; stabilizes scapula.	Dorsal scapular nerve.
Rhomboid major	O: Spines of T2–T5. I: Vertebral border of scapula inferior to spine.	Elevates and adducts scapula and rotates it downward; stabilizes scapula.	Dorsal scapular nerve.
Trapezius	O: Superior nuchal line of occipital bone, ligamentum nuchae, and spines of C7–T12. I: Clavicle and acromion and spine of scapula.	Superior fibers upward rotate scapula; middle fibers adduct scapula; inferior fibers depress and upward rotate scapula; superior and inferior fibers together rotate scapula upward; stabilizes scapula. RMA: Superior fibers can help extend head.	Accessory (XI) nerve and cervical spinal nerves C3–C5.

Posterior deep muscles	Origin & Insertion	Action	Innervation
Longissimus capitis	O: Articular processes of C4–C7 and transverse processes of T1–T4. I: Mastoid process of temporal bone.	Acting together, extend head and vertebral column; acting singly, laterally flex and rotate head to same side as contracting muscle.	Cervical spinal nerves.
Splenius cervicis	O: Spinous processes of T3–T6. I: Transverse processes of C1–C2/C1–C4.	Acting together, extend head; acting singly, laterally flex and/or rotate head to same side as contracting muscle.	Inferior cervical spinal nerves.
Middle scalene	O: Transverse processes of C2–C7. I: Rib 1.	RMA: Flex cervical vertebrae; acting singly, laterally flex and slightly rotate cervical vertebrae.	Cervical spinal nerves.
Posterior scalene	O: Transverse processes of C4–C6. I: Rib 2.	Acting together, right and left posterior scalene elevate second ribs during deep inhalation. RMA: Flex cervical vertebrae; acting singly, laterally flex and slightly rotate cervical vertebrae.	Cervical spinal nerves
Longissimus cervicis	O: Transverse processes of T4–T5. I: Transverse processes of C2–C6.	Acting together, longissimus cervicis and both longissimus thoracis muscles extend vertebral column of their respective regions; acting singly, laterally flex vertebral column of their respective regions.	Cervical and superior thoracic spinal nerves..
Iliocostalis cervicis	O: Ribs 1–6. I: Transverse processes of C4–C6.	Acting together, muscles of each region (cervical, thoracic, and lumbar) extend and maintain erect posture of vertebral column of their respective regions; acting singly, laterally flex vertebral column of their respective regions to same side as contracting muscle.	Cervical and thoracic spinal nerves.
Posterior segmental muscles	**Origin & Insertion**	**Action**	**Innervation**
Semi-spinalis capitis	O: Articular processes of C4–C6 and transverse processes of C7–T7. I: Occipital bone between superior and inferior nuchal lines.	Acting together, extend head and vertebral column; acting singly, rotate head to side opposite contracting muscle.	Cervical and thoracic spinal nerves.
Semi-spinalis cervicis	O: Transverse processes of T1–T5. I: Spinous processes of C1–C5.	extend vertebral column, acting singly, rotate head to side opposite contracting muscle.	Cervical and thoracic spinal nerves.
Multifidus	O: Sacrum; ilium; transverse processes of L1–L5, T1–T12, and C4–C7.	Acting together, extend vertebral column; acting singly, weakly laterally flex vertebral column and weakly	Cervical, thoracic, and lumbar spinal nerves.

	I: Spinous process of a more superior vertebra.	rotate vertebral column to side opposite contracting muscle.	
Interspinales	O: Superior surface of all spinous processes. I: Inferior surface of spinous process of vertebra superior to the one of origin.	Acting together, weakly extend vertebral column; acting singly, stabilize vertebral column during movement.	Cervical, thoracic, and lumbar spinal nerves.
Intertransversarii	O: Transverse process of all vertebrae. I: Transverse processes of vertebra superior to the one of origin	Acting together, weakly extend vertebral column; acting singly, weakly laterally flex vertebral column and stabilize it during movements.	Cervical, thoracic, and lumbar spinal nerves.
Sub-occipital & intrinsic spinal muscles	**Origin & Insertion**	**Action**	**Innervation**
Rectus capitis posterior minor	O: Tubercle on the posterior arch of the atlas I: Medial part of the inferior nuchal line of the occipital bone and the foramen magnum	Extends the head at the neck, considered to be sensory in function	Branch of the dorsal primary division of the suboccipital nerve
Rectus capitis posterior major	O: Spinous process of the axis (C2) I: Lateral part of the inferior nuchal line	Extends and rotates the head	Posterior primary division of the spinal nerves (dorsal ramus of C1)
Obliquus capitis superior	O: Upper surface of the transverse process of the atlas I: Occipital bone between the superior and inferior nuchal lines	Extends the head and flexes the head to the ipsilateral side	Posterior primary division of the spinal nerves (suboccipital)
Obliquus capitis inferior	O: Apex of the spinous process of the axis I: Interior and dorsal part of the transverse process of the atlas	Rotates the head and the first cervical vertebra	Posterior primary division of the spinal nerves (suboccipital)
Anterior & anteriolateral superficial muscles	**Origin & Insertion**	**Action**	**Innervation**
Platysma	O: Fascia covering the upper parts of the pectoralis major and deltoid I: Mandible and subcutaneous tissue of the lower face	Depresses the lower jaw	Facial nerve (VII), cervical branch
Suprahyoid muscle group: Digastric, Geniohyoid, Mylohyoid, Stylohyoid	-	Elevates and retracts hyoid bone, base of tongue, floor of mouth; depresses mandible	Facial nerve; Nerve to mylohyoid muscle; Branch of C1 through hypoglossal nerve (CN XII)

Infrahyoid muscle group: Omohyoid, Sternohyoid, Sternothyroid, Thyrohyoid	-	Steadies hyoid bone and depresses hyoid; Depresses larynx and hyoid bone, steadies hyoid bone	Ansa cervicalis; Thyrohyoid branch of C1 nerve via hypoglossal nerve (CN XII)
Anterior scalene	O: Anterior tubercles of the transverse processes of the 3rd, 4th, 5th, and 6th cervical vertebrae I: Scalene tubercle on the inner border and upper surface of the 1st rib	Elevates first and second ribs, bends the spinal column laterally	Anterior divisions of the lower cervical nerves (C4-C6)
Strernocleidomastoid	See table posterior superficial muscles		
Anterior deep muscles	**Origin & Insertion**	**Action**	**Innervation**
Rectus capitis anterior	O: Upper surface of the transverse process of the atlas I: Inferior surface of the vase of the occipital bone	Flexes the neck	Loop between the first and second cervical nerves (C1/C2)
Rectus capitis lateralis	O: Upper surface of the transverse process of the atlas I: Beneath the surface of the jugular process of the occipital bone	Bends the head laterally	Loop between the first and second cervical nerves (C1/C2)
Longus capitis	O: anterior tubercles of the transverse processes of the third through sixth cervical vertebrae I: Basilar part of the occipital bone	Flexes the neck and rotates the head	Cervical spinal nerves (C1-C3/C4)
Longus colli	O: From the front of the bodies of the upper three thoracic and lower three cervical vertebrae (C5-T3) I: Into the front of the bodies of the second, third, and fourth cervical vertebrae (C2-C4)	Flexes and slightly rotates the cervical spine	Branches from the second to the seventh cervical nerves (C2-C7)

APPENDIX 2: RISK FACTORS

Risk factor findings by game situations for sustaining a head and neck injury in rugby

Risk factor	Explanation	Study	Reference
The tackle	Tackle event most associated with time-loss head injuries and sport related concussions	Cross sectional analytical - South African amateur rugby	van Tonder et al., 2023a, p. 58
	The greatest burden of injury to the player being tackled, followed by the tackling player	Systematic review & meta-analysis	West et. al. 2020, p. 2
	Tackling is the most frequently reported phase of play associated with concussions	Non-professional, male, one season	Brown et al., 2019, p. 5
	The tackle consistently accounts for more than 50% of all injuries in rugby union. A player's tackle actions, and technical ability identified as a major risk factor for injury and a key determinant of performance	Systematic review & narrative synthesis – RU & rugby 7s; all levels & genders	Burger et al., 2020, p.7
	High-speed and high-impact tackles carry a greater propensity for injury, particularly collision-type tackles with head-to-head or neck contact	Systematic review – adolescent, both genders	Bleakley et al., 2011, p. 563
	The tackler has a 4-fold greater concussion rate compared with the ball carrier	Prospective cohort – 3 seasons, youth rugby	Mc Fie et al. 2016, Results
	The primary mechanisms for a concussion occurring in females in rugby union were being tackled or tackling another player (51.7%).	Systematic review – 1990-2021, Women	King et al., 2022, p. 1760
	The tackler is more likely to sustain head injuries than the ball carrier.	Video analysis: 3 seasons, male professional	Tucker et al., 2017, p. 1157
	Women´s elite: The tackle event associated with the greatest burden of injury. "Being tackled" causing the most injuries (28% of all injuries) and concussions (22% of all concussions)	Prospective cohort – 6 seasons elite level female	Starling et al., 2023, p. 1
	Tackles cause five times more injuries than any other type of contact event – the tackle presents the greatest risk to player	Prospective cohort – 2 seasons male elite	Fuller et al. a), 2007, p. 866
	The tackler is more at risk than the player being tackled.	Systematic review & meta-analysis – amateur male	Yeomans et. al., 2018,
	The initial collision stage of the tackle is significantly more likely to result in HAE than other stages.	Research article - Instrumented mouthguards (iMGs), male and female	Tooby et al., 2023, p. 9
Scrum	40% of all rugby derived acute spinal cord injuries occur in the scrum.	Cross sectional cohort – field testing	Hamilton et al. 2014, p. 1

	The relative propensity for scrum events in rugby union to cause injury is high. Scrums are less common than tackles, but a scrum carries a 60% greater risk of injury than a tackle.	Prospective cohort – 2 seasons male elite	Fuller et al. a) 2007, p. 866
Ruck	Players in a defensive role in the ruck at the time the attack are clearing are more susceptible to concussive impacts.	Video analysis, under 18-rugby	Hendricks et al., 2016, p. 10
	The relative propensity for ruck events in rugby union to cause injury is low. Forward players sustain more injuries in rucks.	Prospective cohort – 2 seasons male elite	Fuller et al. a) 2007, p. 864, 866

Risk factor findings by technique for sustaining a head and neck injury in rugby – list from the literature.

Technique risk factor	Explanation	Study	Reference
Height	Upper body tackles cause greater loading of the brain and neck than lower body tackles	Quantitative exploratory study - MADYMO pedestrian model	Tierney & Simms b), 2017, p. 16
	Player body position is a significant risk factor, with an injury risk that is 1.5 times greater when tacklers and ball carriers are upright, rather than bent at the waist.	Prospective cohort study - Video analysis, 3 seasons, male professional	Tucker et al., 2017, p. 1157
	When tackles are either too high (sternum and above) or too low (below the waist), the risk of head impacts is greater.	Case-control study – 3 seasons – Rugby League, women	McLeod et al. 2023, p. 6
	The upright tackles increase the risk of head injury.	3D retroreflective motion analysis, 455 tackles, male	Edwards et al., 2022, p. 1568
Speed	High-speed tackles and tackles where the tackler accelerate into contact are significantly more likely to cause HIA events	Prospective cohort study - video analysis, 3 seasons, male professional	Tucker et al., 2017, p. 1156
	Qualitative video analysis from match footage has shown that injury risk is increased if either the ball carrier or tackler or both players are moving at high speed.	Repeated measures design - simulated tackle conditions, 135 tackles, male	Seminati et al., 2017, p. 5
	One-third of injuries occur when there is a differential in tackling speeds. The player with the lower momentum is injured four times as often as the player with the higher momentum in this scenario	Literature review	Kaplan et al., 2008, p. 88
	Dominant tackles have the highest head accelerations for the tacklers	3D retroreflective motion analysis, 455 tackles, male	Edwards et al., 2022, p. 1568
	Tacklers were at higher risk when they were sprinting (to the tackle)	Descriptive epidemiology study - 140 249 tackles	Quarrie & Hopkins, 2008, p. 1711
	There was a higher risk of concussion if the tackler accelerated into the tackle, or the tackler was moving at high speed	Video analysis	Cross et al., 2019, p. 1
Head placement	Tackling with incorrect head position relative to the ball carrier resulted in a significantly higher incidence of concussions,	Randomly selected 28 game videos - 3970 tackles	Sobue et al., 2018, p. 1

	neck injuries, stingers and nasal fractures than tackling with correct head position		
	Head on tackles caused most injuries to players when tackling.	Two season prospective design - 546 players, English Premiership	Brooks et al. 2005. p. 765
	Dropping the chin forward into the contact appears to increase the risk of head/neck injury through hyperflexion of the cervical spine.	Descriptive epidemiology study - 140 249 tackles	Quarrie & Hopkins, 2008, p. 1714
	In tacklers, the increased injury risk was associated with making initial contact with the head.	Descriptive epidemiological study - under-18 Craven Week rugby tournament	Burger et al., 2017, p. 284
	A large effect was observed for the neck lateral bending angle at impact, that increased in non-dominant side tackles over stationary dominant tackles	Repeated measures design - simulated tackle conditions, 135 tackles, male	Seminati et al., 2017, p. 14
	The factors most highly associated with concussions were head-in-front tackles (where the tackler's head is placed forward, impeding a ball carrier's forward movements)	Descriptive epidemiology study – 20 randomly selected matches, all levels	Kawasaki et al. 2023, p. 1
	Tackles that result in head-to-head contact have the high risk of concussion.	Video analysis	Cross et al., 2019, p. 5
	The risk of tackler-related concussion increased 8.2-fold with tackles with incorrect head placement. Keeping the tackler's head up to check the ball-carrier's movements will contribute to a lower probability of concussions.	Video analysis - Japanese collegiate rugby union teams - 538 tackles	Suzuki et al., 2021, p. 5-6
Feet placement	The foot position of the tackler is a risk factor for injury. Tackler foot planting can potentially reduce tackler mobility and the chance of placing their head in a safe position, increasing the risk of injury	Detailed epidemiological study - 757 male, English Premiership clubs, three seasons	Tierney & Simms, 2017a, p. 4
	Significantly fewer steps were taken before tackles with incorrect head positioning	Randomly selected 28 game videos - 3970 tackles	Sobue et al. 2018, p. 1

APPENDIX 3: TACKLE READY PROGRAM

World Rugby´s Tackle Ready program´s exercises are structured into four groups:

Activity	Aim	Description & videolink
1. Mobility, rolling, falling and landing	Ensuring participants are able to manage their bodies through contact with other players and contact with the ground. Help players to develop and manage a strong and stable body position and to land on the ground effectively and safely. Use of balls can be added to the landing activities where practically possible.	Animal movements: https://vimeo.com/792225401 Partner carries: https://vimeo.com/792225478 Partner balance: https://vimeo.com/792225592 Partner bodyweight flag: https://vimeo.com/792225656 Teddy bear roll: https://vimeo.com/792225708 Backwards roll: https://vimeo.com/792225778 Triangle roll: https://vimeo.com/792225845 Backwards landing: https://vimeo.com/792225905 Sideways landing: https://vimeo.com/792226045 Forwards landing: https://vimeo.com/792226118
2. Deep neck stabilisa tion	Deep stability muscles help to control and stabilise the neck joints and it is therefor important to train these muscles to lesson the chance of injury. Can be implemented: - as part of the warmup - as preparation for contact skills during the main body of the session - at home with friends/family.	Deep Neck Flexor Nod: https://vimeo.com/792208567 Deep Neck Flexor Nod with a Lift: https://vimeo.com/792208750 Deep Neck Extensor Curl: https://vimeo.com/794127955 Deep Neck Flexor Nod and Lift: https://vimeo.com/792208822 Deep Neck Extensor Curl: https://vimeo.com/794127543 Deep Neck Flexor Nod with a Curl: https://vimeo.com/792209029 Deep Neck Flexor Nod and Ear to Shoulder: https://vimeo.com/792209098 Deep Neck Flexor Nod and Rotation: https://vimeo.com/792209170 Deep Neck Flexor-Extensor Nod Combination: https://vimeo.com/794081529
3. Neck strength ening	Neck strengthening: Can be implemented: - as part of the warmup - as preparation for contact skills during the main body of the session - at home with friends/family	Bear Crawl with Neutral Neck: https://vimeo.com/792254882 Bear Crawl Head to Head Battle: https://vimeo.com/792255105 Cheek to Cheek Holds: https://vimeo.com/792255186 Front Bridge from Knees: https://vimeo.com/792255268 Towel Hold in Four Planes: https://vimeo.com/792254936 Front Bridge with Hand Support: https://vimeo.com/792255347 Partner Neck Bridge Back: https://vimeo.com/792255511 Bear Crawl Towel Holds: https://vimeo.com/792255022 Front Bridge: https://vimeo.com/792255429 Neck Back Bridge: https://vimeo.com/792255561

4. Head reaction exercises	To improve neck strength, muscle coordination and reaction time . Can be implemented: - as part of the warmup - as preparation for contact skills during the main body of the session - at home with friends/family	Partner Nudges: https://vimeo.com/792222247 Bear Crawl Partner Nudges: https://vimeo.com/792222313 Triangle Impulse: https://vimeo.com/792222404 Triangle Impulse Shuffle: https://vimeo.com/792222438 Half Grapple: https://vimeo.com/792222519 Lunging and Partner Nudge: https://vimeo.com/792222357 Breaching the Castle: https://vimeo.com/792222482 Full Grapple: https://vimeo.com/792222570 Landing Touch: https://vimeo.com/792222965 Drop Height and Fight: https://vimeo.com/792223031 Static Pre-loaded Tackle and Offload: https://vimeo.com/792223150