The Effects of a Rugby Season on Neck Strength in Professional Men's Rugby Union

A Season-Long Observational Study with Front Five Case Study

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Abstract

Rugby union is a physically demanding sport that places tremendous strain on players' bodies. While physical and mental well-being receive close attention, the importance of neck strength often goes unnoticed. Contact events such as tackles and scrums exert significant pressure on the neck region, potentially compromising strength and function. This may increase brain and cervical injury risk, as players may struggle to mitigate forceful impacts. Front five players may be particularly susceptible, but limited data exists on how rugby activities affect neck strength throughout the season.

In this longitudinal study, the maximal isometric neck strength of 33 professional male rugby union players was measured over the 2021-2022 professional rugby season, using a custom-designed apparatus. Testing comprised two components: (i) pre-, mid-, and post-season testing of the entire squad to explore positional differences and seasonal patterns, and (ii) a front-five case study involving weekly neck strength testing to monitor changes and their associations with-game events.

The findings revealed a significant decrease in neck strength among the forwards in all directions from pre- to post-season, while no significant changes were observed among the backs. At the season's outset, the forwards exhibited significantly greater neck strength compared to the backs, with only neck extension remaining significantly stronger by the end. The front-five case study identified associations between decreased neck strength and in-game events in some players.

This study provides valuable insights regarding observed decrements in neck strength among professional male rugby players, despite limited statistical power. Further research is needed to enhance the generalisability of these findings. Moreover, the study demonstrates the feasibility and reliability of a weekly neck strength monitoring protocol, which can help identify weaknesses and imbalances to prevent neck and head injuries. These findings highlight the potential for establishing a standardised methodology for monitoring neck strength within the rugby community.

Declarations and Statements

DECLARATION:

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed ....[redacted]................................. (candidate)
Date: 18.06.2024

STATEMENT 1:
This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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STATEMENT 2:
I hereby give consent for my thesis, if accepted, to be available for electronic sharing.

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STATEMENT 3:
The University’s ethical procedures have been followed and, where appropriate, that ethical approval has been granted.

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List of Abbreviations

RFU	Rugby Football Union
WRU	Welsh Rugby Union
SRC	Sports Related Concussion
PCS	Post Concussion Symptoms
HIA	Head Injury Assessment
URC	United Rugby Championship
INSTA	Isometric Neck Strength Testing Apparatus
CV	Coefficient of Variation
ICC	Intraclass Correlation Coefficient
SEM	Standard Error of the Mean
N	Newtons
ANOVA	Analysis of Variance
THP	Tight Head Prop
LHP	Loose Head Prop
SR	Second Row
BR	Back Row
HB	Half Backs
B3	Back three

1. Introduction

1.1. Research Context

Rugby Union is a high intensity contact sport requiring high levels of strength, endurance, speed, agility and power. The monitoring of these attributes has become increasingly important to track performance and to manage the workload of individuals to prevent injury, including neck strength (Suchomel et al., 2016). Due to the high intensity nature, it is possible that neck strength can be affected due to training and matches. Contact events such as tackles and scrums exert significant pressure on the neck and cervical spine through axial loading (Cazzola, Preatoni, Stokes, England, & Trewartha, 2015), potentially compromising strength and function. This may increase brain and cervical injury risk, as players may struggle to mitigate forceful impacts. Front five players, who are the most involved in these events, may be particularly susceptible. Currently, limited data exists on how rugby activities affect neck strength throughout the season, and it is not known what these effects are and how this may change neck strength week-by-week. The implementation of weekly testing focusing on the neck strength of front five players in rugby aims to provide actionable insights into the dynamics of strength changes throughout a season. This monitoring process could identify strengths and weaknesses in individuals neck strength, which may help to inform decisions for the professional club associated with this study. Conversely, the process may reveal that the existing training protocols remain adequate throughout the season.

The assessment of seasonal trends in neck strength without a training intervention within a professional rugby team has not been published. The understanding of how trends and changes in neck strength occur over a season in the current climate and setup of rugby teams remains unknown. Furthermore, while previous research has compared neck strength between positional groups, these assessments are generally not longitudinal. Consequently, the positional difference in how neck strength fluctuates over a season is unknown. Forwards generally exhibit greater neck strength than backs (Chavarro-Nieto et al., 2021; Geary, Green, & Delahunt, 2014; Maconi et al., 2016; Olivier & Toit, 2008; Salmon, Sullivan, Handcock, Rehrer, & Niven, 2018), but the maintenance of these differences over the course of a season has yet to be explored.

While not evaluated in this study, previous research highlights the potential of neck strength in mitigating head acceleration incidents and, consequently, reducing head injuries (Chavarro-Nieto et al., 2021; Elliott et al., 2021; Peek et al., 2020). Increased neck strength can reduce linear and rotational head accelerations (Caccese et al., 2018; Chavarro-Nieto et al., 2021; Dempsey et al., 2015; Dezman et al., 2013; Elliott et al., 2021; Peek et al., 2020; Salmon et al., 2018). Consequently, neck training programs have been investigated to assess the benefit and if interventions can have an impact.

The focus on head injuries, particularly concussions, has been at the forefront of research for a number of years with World Rugby stating concussion research as a main focus (World Rugby, 2023). Media reports have intensified further due to an ongoing lawsuit involving the Rugby Football Union (RFU), Welsh Rugby Union (WRU), and World Rugby, which encompasses over 200 players (The Guardian, 2023). The allegations against these governing bodies suggest a failure to implement adequate measures to safeguard players from repeated head impacts, potentially leading to long- term complications such as early-onset dementia. Given the current climate, research efforts have aimed to understand the mechanisms which cause head injuries and develop mitigation strategies to reduce the incidences of head injuries to better protect players.

Despite the recognised importance of neck strength, there is a dearth of comprehensive research studying its correlation with performance and injury prevention in rugby union players. This study aims to fill a gap, providing research into the possible variations in neck strength over a season in rugby union players. This research has the potential to provide actionable insights regarding neck training and interventions in professional rugby, aiming to enhance performance and mitigate injuries. These insights will be particularly valuable if such a need for interventions is identified within this study.

1.2. Aims and Objectives

The current study consisted of two main components. Firstly, a season-long study was conducted, involving the entire playing squad. Secondly, a case study element was implemented, focusing on weekly post-game testing of the front five players throughout the season. The study design for both components was observational, aiming to investigate potential changes in neck strength over a season in a professional rugby team.

This research aimed to gain these insights within the professional rugby training environment.

i. *Pre-, Mid- and Post-Season Study:* The full squad underwent maximal isometric neck strength testing at pre-, mid-, and post- season time points. This was to investigate positional differences and seasonal patterns in neck strength. Backs and forwards were compared as well as individual positions. Directional neck strength was compared to understand the neck strength dynamics using the current testing method. Finally, correlations between neck strength, height and body mass were assessed within the current cohort.

ii. *The Front-Five Study:* The front five players underwent additional weekly neck strength testing in the days following matches, to investigate associations between in-game events and injuries. This also enabled weekly fluctuations in specific, directional neck strength to be quantified, for front-five playing positions.

A constant overarching aim of the study was to develop and validate a reliable neck strength testing methodology. Currently there is not one universal method for testing neck strength. Throughout the current study it was aimed to understand if the current methodology could provide reliable and repeatable neck strength data in a professional rugby environment.

1.3. Thesis Structure

Chapter 2 of this thesis offers background to the current study and a rational for the need of this research. The structure of this begins with and introduction into the game of rugby in Chapter 2.1 followed by the functional anatomy of the neck and cervical spine. This leads to the factors affecting neck strength in Chapter 2.3, followed by how neck strength is related to sports related concussion (SRC) and cervical injuries in 2.4. Lastly, Chapters 2.5 and 2.6 critique the current testing methodologies of neck strength in rugby union and how these results are interpreted.

The methodology (Chapter 3) provides an overview of participant information and the neck strength testing protocol. The chapter begins by explaining the testing apparatus, followed by a detailed description of the testing protocol, including warm-up procedures and setup instructions. Additionally, the collection of additional measurements, such as injury data, minutes played, and game events, is outlined. The chapter concludes by describing the statistical analyses performed on the collected data. Chapter 4 presents the findings from both the pre-, mid-, and post-season study and the front five case study through both statistical analyses and descriptive statistics. Chapter 5 comprises of discussions on the findings from the study. The chapter outlines possible implications and suggested actions that can be derived from the study. Furthermore, Chapter 5.7 addresses the limitations of this study, while Chapter 5.8 explores potential future considerations. Finally, Chapter 5.9 concludes the study, summarising the main findings and drawing overall conclusions.

2. Literature Review

2.1. Rugby Union

2.1.1. Rugby Introduction

The collision sport of rugby union (rugby) is one of the most popular sports globally, being played in 123 countries with 9.6 million players (Hume et al., 2017; Statistica, 2020; World Rugby, 2018). The men's game was professionalised in 1995 (World Rugby, 2020a) facilitating the evolution of coaching, training, recovery, and training technologies (Pritchard & Morgan, 2022; Stoney & Fletcher, 2021; Tavares et al., 2017). The corresponding increase in the physicality of the game, coupled with improved injury reporting awareness and quality, has led to a rise in reporting of severe and non-severe injuries (Hill et al., 2018; West et al., 2021; S. Williams et al., 2022). Of particular concern to the global rugby community is the potential long-term effects of repeated injuries to the head and neck (Cunningham et al., 2018). Therefore, an increased research effort to understand the mechanisms by which these injuries occur, and the implementation of mitigation strategies is critical. The potential impact of neck strength on injury mechanics is an area of growing interest. Neck strength has been identified as a modifiable variable in mitigating the inertial loading of the head during impact events (Chavarro-Nieto et al., 2021; Williams, Petrie, et al., 2021).

2.1.2. Rugby Union Description

Rugby is an 80-minute ball sport played between two 15-a-side teams. It is an intermittent game involving passing, running, and kicking interspersed with rucks, scrums, mauls, and lineouts (Gilbert, 2018). The style of the game sees short periods of high intensity running and sprinting, halted by high intensity impact collisions and regular lower intensity jogging or walking (Austin et al., 2011). This combination of events means players on average spend the majority of a match above 80% of their maximum heart rate (Dubois et al., 2017). World Rugby define the game as an 'invasion and evasion game', with the aim being to move the ball forwards, by carrying or kicking, to score points. Meanwhile, the defending team opposes this, aiming to push the attacking team backwards through tackling to change possession of the ball (World Rugby, 2020b). The changing nature of the game therefore requires a unique blend of strength, power, speed, agility, and endurance in order to be competitive (Frounfelter, 2008).

2.1.3. Physical Requirements of Rugby

Rugby players need various physical attributes depending on playing position, including endurance and sprint speed. GPS data shows that players cover an average distance of 5400 to 6300 metres per match, with 45 to 53% of this being low intensity running (Quarrie et al., 2013). The average number of tackles made per match is 7-13 per player (Headey et al., 2007; Winter, 2022), with the tackle area being the most common event of physical engagement (Hollander et al., 2021). Rugby players have become bigger, faster, and more powerful, with body mass increasing by 10.14 kg per player since 1995 (Hill et al., 2018). However, with the increased physicality and demands, the risk and severity of injuries have also increased (Smart et al., 2013; West et al., 2021).

The demands of a rugby union season cause great fatigue on individuals. Cumulative workloads from matches and training leads to individuals experiencing greater fatigue in the later stages of a season compared to pre-season (Cosgrave & Williams, 2019; Edwards, 2018). Previous research has shown that rugby players require 72 hours to fully recover from matches, a time frame that is often unavailable before the subsequent training or competitive fixture (Aben et al., 2022). This inevitably contributes to fatigue accumulation over the season. Decreased muscle's function has also been shown following matches and over a season in rugby players highlighting a decrement in overall performance (Oxendale et al., 2016). An area that hasn't currently been examined over a season, without intervention, is neck strength. It is currently not known what this cumulative fatiguing effect of matches and training may have on neck strength over the duration of a season.

2.1.4. Positional Requirements

Though the physical requirements in rugby union are similar for each player, there are differences in positions, meaning different players will have stronger attributes in some areas than others. These differences can generally be seen between the backs and forwards. Lindsay, Draper, Lewis, Gieseg, & Gill, (2015) found that backs generally cover more distance than forwards during a game. With regards to impact events however, (carries, tackles, and rucks) forwards were the group that were involved in significantly more than backs.

The main difference between the requirements of forwards and backs is the scrum. This is particularly true for players in the front five (props, hookers and second rows). Engaging in the scrummage puts substantial strain on cervical, thoracic and lumbar spines through significant axial loading, carrying the risk of severe injuries and spinal degenerations (Carroll et al., 2009; Cazzola, Preatoni, Stokes, England, & Trewartha, 2015; Posthumus, 2008; Trewartha, Preatoni, England, & Stokes, 2015). It has been reported that as much as 40% of rugby-related spinal cord injuries can be attributed to scrum-related incidents (Patel et al., 2023). Due to this, research efforts to decrease the mechanical stress during the scrummage led to rule changes at the scrum engagement. The now current laws include a pre-binding action before engagement. This action has resulted in a reduction in impact magnitude by up to 20% when compared to the previous crouch-touch-pause-engage law (Cazzola et al., 2015). Nevertheless, considering the direct involvement of the front five players in this event, and the recognised cervical spine stress it imposes, distinctive conditioning and recovery programs are required for different playing positions (Quarrie et al., 2013).

2.1.5. Injuries in Rugby Union

Due to the high intensity contact nature of rugby union, injuries have always been present in the sport. Injury surveillance reports have found that while injury incidence has remained constant, injury severity has increased, with players missing on average 13 days more (RFU, 2020; The Sports Office, 2017; West et al., 2021). Sports-related concussion (SRC) has been the most commonly reported injury for the past nine season (RFU, 2020). During the 2019 Rugby World Cup, head and neck injuries accounted for 26.6% of the total reported injuries, with head/face injuries being the most prevalent individual injury at 22.4% (C. Fuller et al., 2020). The incidence of head and neck injury, with a particular focus on concussive injuries, is the most commonly reported injury type in rugby union currently (Fuller et al., 2020; RFU, 2020; West et al., 2021). Greater neck strength may play a role in reducing these head and neck injuries, however, the changes in neck strength during a season are unknown.

2.2. Cervical Spine Functional Anatomy

2.2.1. Neck Movement and Function

The neck has three main functions; 1) to enable head movement, 2) to carry large loads, and 3) to protect neural structures whilst performing other functions (Panjabi et al., 1998). The structure of the neck is comprised of three systems: the skeletal, musculature and nervous systems. These three systems work in conjunction to control the head. If any one of these systems is compromised, then part of the movement or control may be lost (D. G. Woolard, personal communication, April 02, 2022). Stabilisation of the cervical spine is supported by the ligaments and muscles that surround it. The ligaments provide passive support to the neck at the end of the range of motion (Kuo et al., 2019). The neck musculature is involved in the dynamic movement's flexion, extension, left and right flexion, and rotation, and provide active stabilisation (Coakwell et al., 2004). The nervous system controls the muscular system and the skeletal system in the neck which results in all movement and control.

This study focuses on the assessment of maximal isometric neck strength excluding rotation due to challenges in measuring and isolating the specific muscles involved. Rotation involves a combination of neck muscles, making it harder to identify specific weaknesses in individual muscles. Also, measuring rotation poses a challenge due to the difficulty in mitigating soft tissue artifact. A study testing head impact sensors revealed that skin patches mounted on soft tissue could displace between four and 13mm relative to a reference point (Wu et al., 2016). This highlights the potential complications associated with coupling to the skull and the potential for measurement errors in rotation due to of soft tissue artifact. There are also potential dangers of measuring rotational neck strength maximally. To measure rotational neck strength, a rotational load, torque, is being applied to a delicate structure of the cervical spine to produce axial rotation (Strimpakos, 2011). Due to this fact, rotational neck strength is not generally measured.

2.2.2. Neck Musculoskeletal Anatomy

The basic anatomy of the neck can be split into the osteoligamentous system and the neck musculature. The osteoligamentous system comprises of the vertebrae and the supporting ligaments. Panjabi et al., (1998) found that this system contributes to 20% of neck stability. These components have multiple functions that occur simultaneously, to allow head movement, maintain stability, load bear and to protect the spinal canals nervous system (Panjabi et al., 1998).

The C1-C7 vertebrae (Figure 1) make up the osteoligamentous system, allowing for movement and resisting compressive forces in load bearing (Coakwell et al., 2004). Vertebrae C3-C6 exhibit typical characteristics, while C1, C2, and C7 possess unique features (Dabasia & Harvery, 2015). C1 (atlas) and C2 (axis) lack intervertebral discs and display differing structural attributes compared to the other vertebrae (Dabasia & Harvery, 2015). The combination of vertebrae and ligaments in the cervical spine permit a wide range of motion and robust load bearing capacity. Consequently, the cervical spine is recognised as the most flexible region of the spine enabling extension, flexion, rotation, and lateral flexion movements (Coakwell et al., 2004).

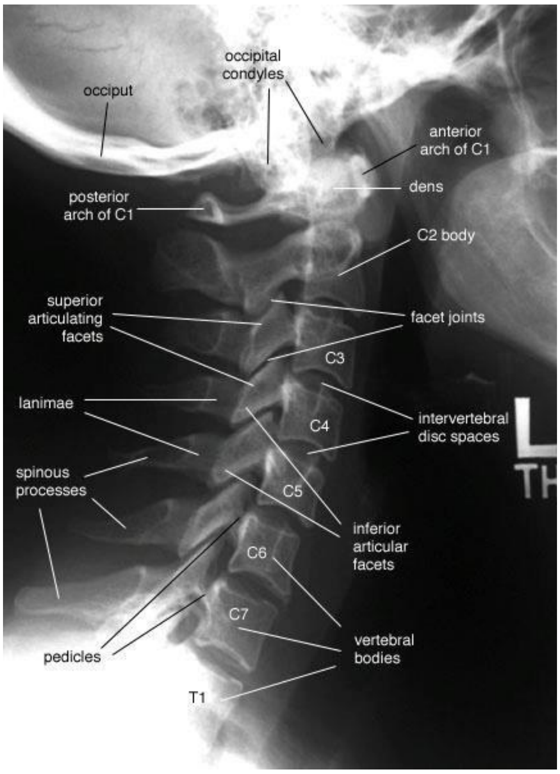

Figure 2-1: Cervical vertebrae, (Richardson, 1997)

Musculature makes up 80% of head and neck stability (Panjabi et al., 1998). The muscles can be placed into 3 groups depending on the movement they perform: flexion, extension, and lateral flexion.

Flexors

Neck flexion is the action of moving your chin towards your chest which primarily involves the muscles located at the front of the neck. The key muscles groups involved are:

- **Sternocleidomastoid**: These muscles run from the base of the skull behind the ear to the sternum and clavicle. They are the main force producer in neck flexion when acting together, and when only one is engaged, it results in rotation or lateral flexion of the neck (Conley et al., 1995).
- **Longus Capitis and Longus Colli**: These muscles are located at the front of the vertebral column. They contribute to flexion of the neck and stabilisation of the cervical spine (Conley et al., 1995).
- **Scalene Muscles**: These muscles (anterior, middle, and posterior) assist in neck flexion, specifically the anterior scalene. Both the middle and posterior scalene are only involved in lateral flexion of the neck (Roesch & Tadi, 2022).

Other muscles that facilitate flexion are the rectus capitis anterior and rectus capitis lateralis. These muscles are not the main force producers but help in producing flexion (Kenhub GmbH & Sendic, 2021). These muscles work synergistically to enable neck flexion, and also they also contribute to maintaining the stability and posture of the head.

Extensors

Extension of the neck involves moving your head backward, or lifting your face upwards. The muscles primarily involved in this action are located at the back of the neck. The main muscle groups are:

- **Splenius Capitis and Splenius Cervicis**: These muscles are located at the back of the neck and help extend and rotate the neck.
- **Semispinalis Capitis**: This deep muscle extends from the back of the neck to the base of the skull and aids in neck extension and rotation.
- **Upper Trapezius and Levator Scapulae**: Although primarily shoulder muscles, these muscles also play a role in neck extension due to their attachment points (Conley et al., 1995).

These muscles not only extend the neck but also contribute to maintaining the posture and stability of the head and upper spine (Lavallee et al., 2013).

Lateral Flexors

Lateral neck flexion, or side bending, involves moving your ear towards your shoulder without turning your head. The muscle groups involved in this movement are:

- **Sternocleidomastoid**: When acting individually, this muscle's function is ipsilateral flexion (Conley et al., 1995).
- **Upper Trapezius**: Though primarily a shoulder muscle, when acting unilaterally, the trapezius can produce ipsilateral flexion of the head and neck (Kenhub GmbH & Sendic, 2021).
- **Scalene Muscles:** These muscles also contribute to lateral flexion of the neck, with the function of the largest of the three scalene muscles, the middle scalene, function being ipsilateral flexion (Roesch & Tadi, 2022).
- **Levator Scapulae**: This muscle elevates the scapula and helps in lateral flexion and rotation of the neck.
- **Splenius Muscles**: These muscles help in lateral flexion when acting unilaterally.

2.2.3. Cervical Spine Nervous System

The nerves in the cervical spine are protected by the cervical vertebra. The cervical nerves are termed C1 to C8 despite there only being seven cervical vertebrae. The cervical nerves pass through the transverse foramina of the cervical vertebrae with the exception of C7 which passes around the vertebrae (Roesch & Tadi, 2022). Each of the eight cervical nerves has the role of controlling different parts of the body depending on where they branch from. For head and neck control, C1, C2 and C3 are the nerves involved. C2 and C3 also have dermatomes which control the sensations on the top, side and back of the head (Slosar, 2016). The signals that the cervical nerves send to the neck controls the head in flexion, extension, lateral flexion, and rotation. The cervical nerves may play a significant role in reducing head accelerations. The faster reaction times of neck muscle activation has been shown to reduce head accelerations (Alsalaheen et al., 2019). This reaction time of muscle activation relies on the signals being sent from the CNS.

2.2.4. Normative neck profile paragraph

Understanding the typical neck strength profile for both healthy adults and rugby union players gives important context when interpreting changes in neck strength in the current study. In healthy adult populations, normative data indicates the neck extensor muscle group to be the strongest generally. This is followed by the lateral neck flexors and the flexors generally being the weakest (Seng et al., 2002). This neck profile is also generally seen in athletic populations, such as rugby players, but is more pronounced. Chavarro-Nieto et al., (2021) found that when testing in an upright, seated position, rugby players consistently showed a similar profile as is described. Particularly, in rugby union forwards, the neck extensors are the dominant muscle group (Mills et al., 2019). This is primarily due to the scrum event and the strength needed to withstand the forces applied. Forwards necessitate substantial eccentric, isometric and concentric strength in the extensor muscles to withstand the high levels of axial loading and significant strain placed on the cervical spine during a scrum event (Cazzola et al., 2015; Posthumus, 2008a; Preatoni et al., 2013; Trewartha et al., 2015).

2.3. Factors Affecting Neck Strength

2.3.1. Neck Strength over a Rugby Season

Due to the physical demands of a rugby season for each individual position there are numerous factors that could affect neck strength. Players experience a substantial number of contact events both in trainings and in matches, with forwards in particular exposed to scrums and mauls. These events have the potential to impact neck strength during the season, however, there are no current studies observing neck strength over a season of professional rugby union with no interventions in place.

In studies that tested neck strength over one season show varied results, though these studies have only been in non-elite sports teams. Salmon et al., (2018) measured peak force pre- and post-season in non-professional rugby players. In this study, both forwards and backs showed improvements across a season without any interventions. These improvements occurred through six hours of match and training time per week, over a 20-week season. The process implies that cervical neck muscles undergo sufficient stress to trigger strength adaptations, without excessive strain. However, it remains uncertain whether playing rugby alone can induce these changes in professional players, as they likely have higher baseline neck strength and perform at higher intensities. Additionally, the improvement in neck strength is not seen consistently in research. Some studies have. found no significant changes in cervical neck strength over a rugby season, even with interventions (Barrett et al., 2015; Naish, Burnett, Burrows, Andrews, & Appleby, 2013). It is suggested that the combination of interventions, along with the training and match play experiences by rugby players, may subject the muscles to excessive stress hindering strength gains. Additionally, over the duration of the season, individuals will experience cumulative fatigue due to match play and training (Edwards, 2018). The effects this may have on neck strength are not currently known, but studies testing the function of other muscle groups have identified decreased over the duration of a season. The effect of fatiguing accessory muscles on the neck is also not known.

2.3.2. Post-Match Neck Strength

Specific research on post-game neck strength in rugby union is currently not available. A systematic review by Chavarro-Nieto et al., (2021) did not include studies solely focused on post-game neck strength. Even in studies that assessed players over a season, data collection typically occurred at specific stages, such as quarterly testing, which may not capture post-game measurements. While not specific to rugby, Netto, Carstairs, Kidgell, & Aisbett, (2010) investigated neck strength after a single bout of exercise and found a significant decrease in neck strength one hour and one day post-exercise. This suggests that there could be a notable decrease in overall musculature, including neck strength, immediately and one day after rugby union matches. Although not specific to neck strength, Aben et al., (2020) found that 72hours was needed for recovery post rugby union matches. Within a season, this time frame is not always possible due to training and preparation for the next game. Therefore, fatigue accumulates during the season. Additionally, the accessory muscles which are involved in stabilising the head and neck will also be fatigued following strenuous efforts, such as a rugby match, which can also affect neck strength.

2.3.3. Rugby Playing Position and Neck Strength

In neck strength studies for rugby union there is a consensus that forwards generally possess greater neck strength than backs (Chavarro-Nieto et al., 2021; Geary et al., 2014;

Maconi et al., 2016; Olivier & Toit, 2008; Salmon et al., 2018). Salmon et al., (2018) showed that some explanations for this are that forwards are generally heavier and have larger neck girths than backs. These factors are the main contributors for the greater neck strength that forwards generally poses compared to backs. However, when relative to body mass, these differences have been found to normalise (Fuller et al., 2022).

Within rugby forwards, Olivier & Toit (2008) found that it was second row players who performed the best in all directions other than extension. Front row forwards had the strongest extensors. This was an early study assessing positional differences and the methodology used did not limit the use of accessory muscles. There are limited studies that compare every position, however. This may be due to the difficulty in gathering a great enough sample size when looking at every position individually. The study by Olivier & Toit (2008) is therefore the main study to date that has compared positions in rugby players.

2.3.4. Effect of Neck Size and Head Mass on Neck Strength

Tierney et al., (2008) show that a decreased head mass can lead to higher head accelerations. This has been reiterated in a recent study by Caccese et al., (2018) in heading footballs. The reasons for this can be explained by Equation 1and Equation 2.

Equation 1

- Force (N) = mass (kg) × linear acceleration (m/s^2)

Equation 2

- Torque (T)= moment of inertia (I) × rotational acceleration (a)

These equations show that the higher head mass will result in lower linear and rotational accelerations (Caccese et al., 2018). Despite this, head mass is predominantly determined by genetic factors and, as such, is not easily modifiable, posing challenges when using it as a variable to reduce head accelerations. Individuals with greater head mass may naturally have a lower risk of injury, which can provide valuable information for professional sports teams during player screening.

Additionally, there are other ways to interpret Equation 1. Babbs, (2001) suggest the importance of calculation an individual's effective mass. This being the mass of the head and body that could oppose a force. Within football heading, they found that the greater the effective mass, the smaller the acceleration to the head. Thus, suggesting the importance of strong activated muscles, which can improve head-to-neck coupling, so that the entire body mass is connected during an impact.

Research has demonstrated that larger neck size and girth can decrease linear and rotational head accelerations (Dempsey et al., 2015; Viano et al., 2007). Salmon et al., (2018) demonstrated that neck girth was associated with peak neck strength. This was attributed to increased cross-sectional stiffness and reduced peak velocity of head accelerations. However, this is not seen consistently, and there is currently no consensus that an increased neck girth correlated to increased neck strength (Collins and Hamilton). With regards to head accelerations, In football, Caccese et al., (2018) observed a 22% reduction in accelerations from heading the football with increased neck girth, along with an effect of head mass. Similar findings have been reported in rugby, where greater neck girth correlates with higher peak force and the potential to reduce head accelerations Salmon, Sullivan, Handcock, Rehrer, & Niven, (2018). The existing literature supports the consensus that greater neck strength in associated with increased muscle mass (hypertrophy). However, there is no clear consensus regarding the direct relationship between neck girth, neck strength and reduced head accelerations.

2.3.5. Neck Strength Imbalances

Imbalances in neck muscles have been proposed as an indicator of potential concussion risk (Dezman et al., 2013). In collegiate football players symmetrical neck flexion and extension was shown to reduce head accelerations (Dezman et al., 2013). Mean neck strength measurements revealed a positive correlation between strength differences and angular head accelerations (Dezman et al., 2013). The significance of neck strength symmetry is further highlighted by the study, which found no significant correlation between flexion or extension strength and head acceleration independently. Thus, overall neck symmetry can play a crucial role in head-neck stabilisation (Dezman et al., 2013). It is important to note that these findings were observed in collegiate football players and at low velocities, limiting their generalisability to a broader population and high-impact sports like rugby union, where impact velocities are greater. Gillies et al., (2022) found that in rugby union, players who went on to sustain a head or neck injury, including SRC, had a flexor/extensor ratio below 0.6. This potentially suggests the need for greater balance between the flexors and extensors. Despite these findings, studies that have suggested neck strength is not a predictor of concussion risk do not include muscles strength imbalances, only absolute strength (Garrett et al., 2023; Liston et al., 2023). Additionally, there are limited studies on the impact of left/right flexion imbalances and head acceleration. In a systematic review by Caccese & Kaminski (2016), there were no studies assessing left and right flexion imbalances. Therefore, it is unknown if left/right flexion imbalances could suggest to concussion risk.

2.3.6. Neck Muscle Activation

Although not tested as part of the current study, activation of cervical muscles prior to or in response to contact has been shown to effectively reduce head accelerations. Alsalaheen, Mccloskey, & Bean, (2019) found that anticipating an impact reduced head accelerations in both men and women, resulting in lower angular velocity and extension excursion. Eckner, Oh, Joshi, Richardson, & Ashton-Miller, (2014) demonstrated that "bracing for impact" also reduced the magnitude of head accelerations. Specifically, in rugby union, Hasegawa et al., (2014) revealed that clenching the neck muscles significantly decreased head accelerations. Additionally, in the context of youth ice hockey, Mihalik et al., (2010) discovered that players who did not anticipate impacts of moderate to severe severity experienced higher angular accelerations, increasing their risk of head accelerations and brain injury. Consequently, Alsalaheen et al., (2019), Eckner, Oh, Joshi, Richardson, & Ashton-Miller, (2014) and Mihalik et al., (2010) suggest implementing strategies to improve players spatial awareness, which may improve impact anticipation.

Despite the existing evidence indicating that anticipation can reduce head accelerations, the available data pool in this area, particularly within contact sports, remains limited. The majority of data currently available is derived from laboratory settings, which can offer insights into field-based events but are not directly comparable. The reliance on laboratory-based research is primarily attributed to the challenges associated with measuring anticipation in field-based research conditions.

2.3.7. Neck Strength and Other Injuries

The influence of non-neck injuries on neck strength has not been extensively studied. However, it is established that shoulder pain and injury can impact head and neck recovery after a concussion (Provance et al., 2020). Limited research exists on the effects of injuries on muscle strength, including the impact of illnesses. Ethical considerations may prevent participants from training while being ill or having existing injuries, contributing to this scarcity of data. Nonetheless, in this study, if players with minor injuries or illnesses were able to continue training, the professional team emphasised the continuation of neck strength training. Hence, any injuries or illnesses recorded by the professional team themselves could potentially affect neck strength and would be reflected in the collected data.

2.4. Neck Strength, Sports-Related Concussion and Cervical Injuries

Neck strengthening has been increasingly recognised as a strategy to reduce head and neck injuries. It is important to first understand the nature and prevalence of sports related concussions (SRC).

2.4.1. Concussion Nomenclature

The term ‘concussion’ is the most used in news reports and in research. The definition for SRC was updated in 2022. The mechanistic aspect of the definition reads as: *“Sport-related concussion is a traumatic brain injury caused by a direct blow to the head, neck or body resulting in an impulsive force being transmitted to the brain that occurs in sports and exercise-related activities”* (Patricios et al., 2023). Quantifying and identifying "concussion" without the involvement of a medical professional poses difficulties. Nevertheless, many studies continue to use "concussion" as their outcome variable, often employing varying definitions interchangeably. To remain consistent throughout this study and with the literature, when reporting other studies, the same terminology will be used with that published.

2.4.2. Concussion Recognition, Assessment and Reporting

SRC symptoms can occur immediately or days following injury. These include loss of consciousness, neck pain, behavioural changes, balance problems and cognitive impairment (Hobbs et al., 2016; Patricios et al., 2023). Prolonged post-concussive symptoms (PCS) can persist for months and in some cases years, and include headaches, fatigue, dizziness, emotional changes, cognitive difficulties, sleep disturbance, and depression/anxiety (Broshek et al., 2017). Recognising symptoms is crucial, as few measures consistently differentiate between concussed and non-concussed individuals (Putukian et al., 2023), and recovery is unique. Factors such as concussion history, age, sex, sleep, learning disability, ADHD, and timing of removal from play affecting recovery time (Iverson et al., 2017). Rugby employs symptom-based and on-field assessments, such as the Head Injury Assessment (HIA) protocol introduced in 2015 (World Rugby, 2015), to identify SRC's, which remain the most common injury in rugby. Over the duration of a season, the RFU injury surveillance report found there to be 19.8 concussions per 1000 playing hours (RFU, 2020). These incidences increase as the season progresses, potentially due to the cumulative fatigue over the season, which may reduce reaction times or increase technical errors (Cosgrave & Williams, 2019). In training, concussion incidence rates have climbed from 0.07/1000 playing hours in 2015-16 to 0.21/1000 playing hours in 2018-19 (Gardner et al., 2014; RFU, 2020). Concussion rate also vary between playing levels, rates increase as the level of play becomes more elite (Elite -19.8/1000 playing hours, Community – 4.4/1000 and 5.3/1000 playing hours in England and Ireland respectively) (RFU, 2020; Rugby & Surveillance, 2018).

2.4.3. Cervical Spine Injury Kinematics

The cervical spine is a common site for injuries both in the general population and in sports. With its anatomy being relatively instable, it is particularly susceptible to severe injury from high-impact loads that can cause damage to cervical muscles, ligaments, and lead to head accelerations (Cusick & Yoganandan, 2002). In the general population, cervical injuries such as fractures and dislocations are uncommon, but neck pain is relatively common and often coexists with other health problems (Barile et al., 2007; Hogg-Johnson et al., 2010; Kruse & Lemmen, 2009; Spoonamore, 2021). In sports, most injuries to the cervical spine occur through low energy trauma and are usually sprains that result in full rehabilitation (Barile et al., 2007; Landim et al., 2019). However, high-energy impacts can lead to serious injuries such as nerve root or spinal cord damage (Badenhorst et al., 2017; Landim et al., 2019). Returning to play after a cervical injury requires careful planning and consideration. Premature return to play can increases the risk of more severe injuries or re-injury, while repeated injury can lead to chronic damage and degeneration of the cervical spine (Kepler & Vaccaro, 2012; Schroeder & Vaccaro, 2016). Consequently, Canseco, Dossett, & Vaccaro, (2020) developed updated guidelines through a modified Delphi process to assess cervical spine injuries. These guidelines aim to provide statements that can help evaluate the ability of collision sport athletes to return to play.

2.4.4. Mechanisms of Head and Cervical Spine Injury in Rugby Union

The tackle has been identified as the highest risk area for both cervical and head injuries in elite men's rugby (Dunn & van der Spuy, 2010; Fuller, Taylor, & Raftery, 2018; Solis-Mencia, Ramos-Álvarez, Murias-Lozano, Aramberri, & Saló, 2019), with player-to-player and player-to-ground impacts causing injury (Cross et al., 2019). Additionally, variables within the tackle event, if done incorrectly or correctly, can lead to injury (Meintjes et al., 2021). These include head position, tackle height, arm positioning, direction, and speed (Cross et al., 2019; Sobue et al., 2018; Suzuki, Nagai, Iwai, Furukawa, et al., 2020; Suzuki, Nagai, Iwai, Ogaki, et al., 2020; G. J. Tierney & Simms, 2017; Tucker et al., 2017). For example, the likelihood of a concussive impact is 4.67 times greater with the head down than with the head up. Arm positioning also affects the risk, the likelihood of a concussive impact was 4.38 times higher when contact was made with the arm first and not maintained throughout the tackle (Suzuki, Nagai, Iwai, Furukawa, et al., 2020). Higher tackle speeds and side-on tackles further elevates the risk of cervical and head injuries (Suzuki, Nagai, Iwai, Ogaki, et al., 2020; Tucker et al., 2017). In men's rugby, impacts to the trunk, lower limb, and pelvis pose less risk of head acceleration and potential concussions (Cross et al., 2019; Tucker et al., 2017). However, if the head impacts a hard body part, such as the knee or elbow, there is a higher risk of concussion, particularly for head-to-head and head-to-elbow impacts (Tucker et al., 2017).

2.4.5. Injury Mechanics and the Scrum

A rugby scrum involves eight players binding together to compete for possession by pushing against the opposition. During this act however, there are several risks due to the intensity and multi-directional force of impact, as well as its potential duration, that could lead to injury (Trewartha et al., 2015). Additionally, players are required to exhibit large eccentric, isometric, and concentric strength qualities. Failure to meet these demands can lead to the scrums collapse and potential injuries (Mills et al., 2019). Front row forwards in particular are at higher risk of acute and chronic injury (Reboursiere et al., 2018). Chronic injury is mainly sustained through overuse. In the early 2000s the scrum also accounted for about 40% of all catastrophic injury. These predominantly affected the spinal cord (Quarrie et al., 2002). Other studies had found that the front row accounted for as many as 41% of all cervical spine, 56% of thoracic spine and 71% of lumbar spine injuries because of the scrum (Trewartha et al., 2015). To mitigate against these injuries, law changes aimed to reduce the initial impact of the scrum. The implementation of these laws has led to a decrease in catastrophic cervical spine injuries in France from 1.9 catastrophic cervical spine injuries per 100,000 to 1.1 catastrophic cervical spine injuries per 100,000 (Reboursiere et al., 2018). In addition to law changes, it has been suggested that players can increase neck muscular endurance to reduce head and neck injury during the scrum, as opposed to solely focusing on absolute neck strength (Chavarro-Nieto et al., 2021; Hamilton et al., 2014; Olivier & Toit, 2008; Peek et al., 2020; Salmon, Handcock, Sullivan, Rehrer, & Niven, 2015; R. T. Tierney et al., 2008; Viano, Casson, & Pellman, 2007).

2.4.6. Neck Strength and SRC

A recent systematic review encompassing various sports revealed that enhanced neck strength correlates with decreased incidences of SRC (Elliott et al., 2021). This review provides clinically worthwhile evidence for including neck training exercises in injury reduction programs. The review indicated that improving strength, activation, and symmetry of neck musculature can enhance the neck's capacity to absorb external forces and enhance head and cervical spine stabilisation (Elliott et al., 2021). Despite this, another systematic review indicated a small and non-significant association between greater neck strength and lower risk of SRC in team sports (Garrett et al., 2023). Notably, rugby union displayed the strongest relationship between neck strength and decreased SRC rates within this review. Both reviews, however, had limited studies that met the inclusion criteria, indicating the necessity for more research in this area. Overall, both reviews suggested that the neck musculature plays a role in reducing concussion risk, however, the magnitude of this effect is unknown. The majority of literature has focused on evaluating isometric neck strength, with limited examination of components such as rate of force development or endurance. This approach limits the understanding of a multifactorial approach to neck strengthening and consequently, it is unclear if neck strength is the paramount factor, or if other qualities may play a more influential role. The reliance on neck strength as a primary outcome may be a function of convenience as this is the most commonly reported variable. Expanding neck assessments to incorporate other neuromuscular factors could highlight different findings and strategies for neck strengthening.

Specifically, within rugby union, increasing neck strength has also been suggested as a way of mitigating against head and cervical neck injuries (Chavarro-Nieto, Beaven, Gill, & Hébert-Losier, 2021). For example, Naish, Burnett, Burrows, Andrews, & Appleby, (2013) showed that when neck strength exercise were incorporated into training over a rugby season, cervical injury decreased from the previous season. One proposed explanation for the link between cervical muscle strength and reduced head acceleration is that greater cervical muscle strength can improve the head-neck coupling, increasing the effective mass of the head-neck segment. According to Newton's Law of Acceleration (Force = Mass x Acceleration), acceleration is directly proportional to the mass of the object and the force applied, meaning that greater mass can lead to reduced acceleration for a given force.

However, there have been recent papers suggesting greater neck strength may not be linked to decreased concussion risk. Liston, Leckey, Whale, & van Dyk, (2023) propose that neck strength is not a strong predictor of concussion risk in male rugby players. Rather, they argue that a player's previous concussion history serves as the strongest predictor. This finding was reliant on participants self-reporting their concussion history which poses questions around the reliability of these data. Additionally, the sample size of 136 participants in the study may be underpowered, considering the number of extraneous variables involved in determining the likelihood of sustaining a "concussion." These points are particularly relevant when considering the magnitude of the conclusions drawn from the study. Similarly, Garrett et al., (2023) found that there was a small, non-significant correlation between increased neck strength and decreased SRC risk. This study however only included eight studies in total for its systematic review and four of those studies in its meta-analysis showing the limited research around combining neck strength with concussion risk.

2.4.7. Neck Training Interventions

Given the potential benefits of improved neck training on head and neck injury mitigation, a number of studies have implemented interventions specifically targeting neck strength in various contact and non-contact sports (Attwood, Hudd, Roberts, Irwin, & Stokes, 2022; Barrett et al., 2015; Geary, Green, & Delahunt, 2014; Naish et al., 2013; Peek et al., 2022; Versteegh et al., 2019). Though not comparable to rugby, increased isometric neck strength has been observed in football Peek et al., (2022) and martial artists (Linen et al., 2003, Lahart & Robertson, 2009) as a result of training interventions. Additionally, these improvements weren't identified in non-athlete populations who were not involved in such interventions. This highlighting the potential neck training interventions have to improve the overall neck profile.

In the context of rugby, Attwood et al., (2022) reported a 24% improvement in neck strength among age-grade players following an 8-week self-resisted neck strength intervention. However, it should be noted that these findings cannot be generalised to elite athletes. Age-grade or amateur players tend to exhibit lower baseline neck strength which may allow for more substantial improvements with a reduced training load, as suggested by Salmon, Sullivan, Handcock, Rehrer, & Niven, (2018). In elite rugby, Gillies et al., (2022) implemented a neck strengthening program over a full season. This resulted in improved neck strength in all directions for both backs and forwards, with significant improvements in flexors and left flexors for forwards, and flexors for backs. In contrast to the findings of Gillies et al., (2022), Naish et al., (2013) observed no significant improvements in neck strength among elite rugby players following a five-week strengthening program. Possible explanations for the minimal, non-significant increase could be that rugby players were already preconditioned, or that they were underloaded, causing the intervention to be less effective.

The timing and stage of the season that these interventions took place must also be considered. For instance, the intervention used by Naish et al., (2013) occurred during the pre-season, limiting extraneous variables like matches. Though no improvement was found in the cohort, it is important to consider the effects other pre-season training could have had on neck strength. For example, the number of contacts or scrum trainings may have negated the effects of the intervention. This study however was based over 2 seasons including many different participants. The main focus was also on cervical neck injuries rather than head injuries. On the other hand, Gillies et al., (2022) intervention took place within the season with players tested at pre- and post-season. The exception to this was the forwards group who underwent additional assessment following pre-season period. Furthermore, there was disruption due to the Covid-19 pandemic that affected the intervention phase. Despite this, the results of pre-, and post-season testing could have been influenced by players involvement in match play. It is worth questioning whether the improvements observed were solely due to the intervention or if playing rugby alone can elicit strength changes, as found in an amateur population by Salmon et al., (2018). Overall, these contrasting outcomes highlight the need for further research to better understand the effectiveness of neck strengthening programs in the context of elite rugby union.

2.5. Research Techniques for Measuring Neck Strength.

Limited methodologies exist for measuring cervical neck strength due to the recent nature of research in this field. Additionally, there is no single universally accepted gold standard methodology for testing neck strength. A systematic review conducted by Chavarro-Nieto et al., (2021) identified the main approaches currently used to measure neck strength in rugby union, which include:

- Head harness or strap attached to load cells in a seated or lying position.
- Handheld dynamometers
- Fixed frame dynamometers
- Customised ergometer

From the current methods, Chavarro-Nieto et al., (2021) found that all bar two were completed in an upright position with the head in a neutral position. Of the two that didn't, one completed the test in a scrummaging position, and one completed the test lying on a bench in a prone position. There are also two primary method types for neck strength measurement, these being the 'make' and the 'break' tests.

2.5.1. Make vs Break Techniques

Two primary methods are utilised to assess isometric neck strength: the 'make' test and the 'break' test. The break test involves the athlete performing a maximal eccentric isometric muscle contraction again a clinical-applied force. This continues until the clinician's force exceeds the athlete's output, causing the contraction to 'break' (Peek, 2022). Conversely, the 'make' test requires the athlete to generate a maximal concentric isometric muscle contraction. This force is produced against a fixed resistance, which may be provided by the athlete themselves, a clinician, or a fixed surface (Peek, 2022). A study by Chavarro-Nieto et al., (2023) demonstrated excellent reliability for both make and break techniques. However, the break test was shown to yield slightly higher results in the flexors and lateral flexors, potentially indicating a more reliable measure of maximal isometric neck strength (Peek, 2022). Despite potentially yielding less valid results, the make test has shown some procedural advantages, such as reduced risk or test-related injuries and enhanced participant comfort and confidence (Chavarro-Nieto et al., 2023). Overall, in their review, Chavarro-Nieto et al., (2023) recommend the use of a make-style technique for the assessment of maximal isometric neck strength.

2.5.2. Head Harness

The head harness method has been utilised in a number of rugby union studies. Barrett et al., (2015), Naish et al., (2013) and Hamilton et al., (2014) all employed this method, however, Naish et al., (2013) utilise a fixed frame, 'make' test method, compared to Barrett et al., (2015) and Hamilton et al., (2014) who employed a 'break' test. The majority of methods utilising a head harness, and the three mentioned here, tested in a seated, upright position. Consequently, all muscles are tested under the same external conditions, and therefore, generally showing a normal neck profile.

In the make test version of the test, the head harness is attached to a load cell, which is further connected to a fixed frame. Participants wear the harness and exert force in the required direction, recorded by the load cell. The method allows flexibility in participant position, either standing or sitting, and is easily reproducible. Furthermore, this method has shown good intratester reliability (Ylinen et al., 1999). Despite this, Naish et al.,

(2013) failed to find significant changes which Chavarro-Nieto et al., (2023) suggest could indicate low sensitivity of this method.

The 'break' version of this test involves wearing the head harness while the head is in a neutral anatomic position, and then the participant being subjected to a manual force with the force being recorded, either using a handled dynamometer or a load cell device. This method has also shown excellent intra- and interrater reliability (Geary et al., 2014; Hamilton et al., 2014) and has been well validated in healthy populations (Garce et al., 2002). Despite this, there can be concern from clinicians regarding the 'aggressiveness' of this test and the potential from injuries during testing (Chavarro-Nieto et al., 2023).

2.5.3. Handheld Dynamometer

This method is less commonly employed in an elite sporting context compared to previous approaches. However, Snodgrass, Osmotherly, Reid, Milburn, & Rivett, (2018) opted to use a handheld dynamometer due to its favourable inter- and intra-rater reliability. In this method, participants exert force against the dynamometer held by another person using their heads. Additionally, this method requires participants to be in a seated position, meaning muscles are tested under the same external conditions. In the study by Snodgrass et al., (2018), this method did not identify significant differences between healthy individuals or those that experienced neck pain or injury. Therefore, Chavarro-Nieto et al., (2023) suggest that this method may not be sensitive enough to identify changes in rugby union players. Despite this, in an occupational health setting, due to the ease of measurement and limited cost associated with this method, there is a practical use. The method can be used to assess neck pain and gauge potential improvements in non-athletes given its practicality in such contexts.

2.5.4. Customised Ergometers

Salmon et al., (2018), McBride et al., (2023) and Williams et al., (2021) all employed a fixed frame, customised ergometer in their studies. Compared to previous methods, these methods all test in a lying/quadruped position. Consequently, the muscles are not all tested under the same external condition, the flexors are tested with gravity, the extensors against gravity, and the lateral flexors perpendicular to gravity. Results therefore have to be interpreted with caution as they do not present a normal neck profile. In particular, these methods generally present the neck flexors as the strongest, followed by extensors and lateral flexors, contrary to a normal profile. However, assuming that these results are only being compared to themselves and are tested under the same external conditions during each test, this does not affect the repeatability and reliability of the results. Additionally, though using a hand held dynamometer, Krause et al., (2019) found that testing in a lying position was more sensitive to change than a seated position, despite muscles not being tested under the same conditions. Consequently, they state that 'consistent methods should be used when comparing tests' (Krause et al., 2019).

Another commonly used fixed frame dynamometer is The VALD ForceFrame. The VALD is device that is already commonly used in various sports teams to measure force exerted by different body parts. This makes it a cost-effective and logistically convenient option for sports teams to assess neck strength, considering its multi-purpose functionality and existing availability. Furthermore, its portability and lightweight nature make it suitable for operational settings (McBride et al., 2023). McBride et al., (2023) found that the VALD produced good to excellent intra- and inter-rater reliability scores and can reliably assess isometric neck strength for healthy individuals. As already mentioned however, the neck muscles are not measured under the same external conditions, and therefore a different neck profile is seen to the norm. Despite this, if kept consistent, the results can be compared to one another.

As with other fixed frame dynamometers however, there is limited or no attempt to reduce the use of accessory muscles. In the case of the VALD, it employs a press-up position from the knees, allowing participants to fully engage their arms and trunk to aid in force production. It is crucial to consider this factor when interpreting results, as the utilisation of accessory muscles could potentially enhance maximum voluntary contraction (MVC) outcomes or, conversely, result in decrease MVC's due to fatigue in other muscle groups on the testing day. Consequently, if the primary aim of the research is to solely measure neck strength, potentially for injury identification/monitoring, then it is important to acknowledge these limitations when interpreting the results.

2.5.5. Isometric Neck Strength Testing Apparatus (INSTA)

The INSTA employed by Williams et al., (2021) was designed based on that of Salmon et al., (2018) and therefore has similar features. Both methodologies test in a quadruped position, however, the test by Williams et al., (2021) limits the use of accessory muscle usage more so than Salmon et al., (2018). The fixation of the trunk, and the lying position has advantages in test repeatability, standardisation and maximising trunk stabilisation (Krause et al., 2019). However, Peek, (2022) raises the point regarding how much trunk stabilisation is needed as the core muscles will also play a role in head/body contact events. Additionally, as previously mentioned, when testing in a lying position the neck muscles aren't tested under the same external conditions. It was found that the neck flexors were the strongest muscle group, followed by the extensors and lateral flexors in the study by Williams et al., (2021). This is due to the flexors being tested with gravity, extensors against gravity, and the lateral flexors perpendicular to gravity. This consequently shows a non-normative neck profile. However, as suggested by Krause et al., (2019), consistent methods should be used between tests, and if so, results can be compares to each other.

Despite this, if the aim of testing is to isolate the neck from the trunk, the methodology by Williams et al., (2021) utilises the most restraints. Additionally, providing the testing conditions are kept the same between tests then neck strength results can be compared week-by-week to each other. The INSTA methodology was selected for use in this study as the aim was to compare neck strength week on week in rugby union players. It was also important to use a testing apparatus that would be sensitive to changes in neck strength which in rugby union player was not found by Chavarro-Nieto et al., (2023) in other testing methodologies mentioned previously.

2.6. Interpreting Neck Strength Data

Accurate interpretation of neck strength data is crucial for this study, as it informs feedback to individuals and the club for future planning. To ensure study credibility, Peek (2022) highlights four important considerations: sport specificity, device portability, neck strength profile, and muscle contraction type.

Regarding sport specificity for rugby union players, previous studies have tested in a quadruped position (Salmon et al., 2015; Williams et al., 2021). When interpreting these results, it's crucial to consider the influence of gravity. Most neck strength research indicates that seated positions yield the greatest strength in neck extensors (Barrett et al., 2015; Hamilton et al., 2014). However, Williams et al., (2021) found that male rugby union players exhibited greater flexor strength than extensor in the scrummage position. This same paper and Salmon et al., (2018) also reported weaker left and right lateral flexors compared to both flexors and extensors. This can be compared to Barrett et al., 2015 and Hamilton et al., 2014 where lateral flexion was greater than flexion. The reasons for these different neck profiles are due to testing position. The neck muscles are not tested under the same external conditions between the different methodologies. In a lying/quadruped position the flexors being tested with gravity, extensors against gravity, and the lateral flexors perpendicular to gravity. It is therefore expected that the flexors are the strongest in this testing position, despite what a normal neck profile would suggest. These variations highlight the significance of specifying the testing position and considering sport specificity when interpreting results.

A crucial aspect of interpretation is the neck strength profile. One effective approach suggested by Peek, (2022) is to use strength radars, which provide a visual representation of neck strength and are valuable for presenting these data to players and clubs. Peek, (2022) also introduces the F/E calculation, which determines the ratio between the neck flexors and extensors. Gillies et al., (2022) demonstrated that an F/E ratio of <0.60 indicates a higher risk of injury. For contact athletes, a ratio closer to one is recommended (Gillies et al., (2022). This ratio could potentially be applied to left and right flexors as well, with a ratio close to one indicating a lower risk of injury.

3. Methods

3.1. Methods Overview

3.1.1. Study Participants

This longitudinal, observational study aimed to measure the isometric neck strength of professional male rugby union players throughout the 2021-22 UK men's professional rugby season. A men's United Rugby Championship (URC) team, ranked tenth in the league for the 2021/22 season, agreed to participate. In total, 33 male professional rugby players participated in the study (age 25.1 ± 3.6 years; Height 184.91 ± 7.40; Body mass 103.14 ± 13.34). Of these participants, 20 were forwards and 13 were backs, with 15 of the forwards playing in front-five positions (props, hookers and second rows). All individuals were part of the first team squad. The study consisted of two components:

i. *Pre, Mid and Post-Season Study:* The full squad underwent maximal isometric neck strength testing at pre-, mid-, and post- season time points. This was to investigate positional differences and seasonal patterns in neck strength.

ii. *The Front-Five Study:* The front five players underwent additional weekly neck strength testing in the days following matches, to investigate associations between in-game events and injuries. This also enabled weekly fluctuations in specific, directional neck strength to be quantified, for front-five playing positions.

3.1.2. Ethics Approval

Ethics approval was obtained from the Swansea University College of Engineering Research Ethics Committee (ref 2016-059 amendment 9). Prior to participating, all players were provided with an information sheet and given the opportunity to ask any questions. If they were willing to participate, they provided written informed consent at the beginning of the season (Appendix A), prior to any measures being taken. Players could opt to allow the coaches to see their individual data. If consent was given, players data was provided to the coaching team in the form of reports following each session. If players did not consent, they were assured that all the data would remain confidential. Outside of the coaching team, participants were assured that all data would remain confidential and anonymous using participant ID codes. Data collection was significantly impacted by COVID-19 outbreaks that occurred during the URC championship. Although all match fixtures were eventually played by the end of the season, several postponements occurred mid-season due to the outbreaks. This resulted in a break in data collection from October 2021 to January 2022.

3.2. Neck Strength Testing

3.2.1. Neck Strength Testing Equipment

A bespoke isometric neck strength apparatus (INSTA) was utilised, as described in detail in Appendix B (Williams, Sotgiu, et al., 2021) (Figure 2) Briefly, the INSTA design was based on a neck strength ergometer used by Salmon et al., (2014), with modifications to reduce neck accessory muscle usage and, to the highest degree that is practical, only test neck muscle strength. The INSTA was designed to provide repeatable and reliable isometric neck strength data for neck flexors, extensors, and lateral flexors. In non-elite humans, who were tested across one week, a coefficient of variation (CV) of 9.6 for anteroposterior and 15.2 for lateral directions was found. In this study, changes of more than 10% and 15%, respectively, were considered as significant according to these CV findings. Table 3-1 shows the CV, intraclass correlation coefficient (ICC).

Figure 3-1:Isometric neck strength apparatus (INSTA)

Table 3-1: Table showing results from human reliability testing for the INSTA.

					ICC				ANOVA	
		Average	**SD**	**CV (%)**	**Single Measures**	**Lower Bound**	**Upper Bound**	***p***	**F**	***p***
Extensors	Test 1	136.8	44.7	9.72	0.916	0.83	0.964	<0.0001	2.389	0.106
	Test 2	143.8	44.7							
	Test 3	145.8	49.0							
Flexors	Test 1	141.9	51.6	9.44	0.901	0.803	0.957	<0.0001	0.4	0.673
	Test 2	142.1	50.2							
	Test 3	145.9	45.5							
Left Flexors	Test 1	101.8	47.0	15.55	0.879	0.762	0.947	<0.0001	2.441	0.101
	Test 2	110.4	48.2							
	Test 3	112.4	44.0							
Right Flexors	Test 1	107.7	46.5	14.76	0.891	0.784	0.952	<0.0001	0.234	0.793
	Test 2	109.4	49.5							
	Test 3	111.5	54.1							

The INSTA was used to test the neck strength of all the participants. Participants lay prone on a padded bench while kneeling on a raised platform Figure 3. Testing was completed in this position primarily to isolate the neck muscles and obtain precise measurements of these muscles independent to any other that might provide support. To reduce the use of accessory muscles, the participant's feet were off the ground. They were also strapped into the INSTA using a harness which wrapped around the lower back and over both shoulders. The participants were instructed to place their arms behind their backs or their hands on hips to limit accessory muscles use as much as possible. Lastly, the headpiece was adjustable to ensure the correct positioning of the load cells. The participant was instructed to keep their head in a neutral position while positioning of the load cells occurred. Specifically, the load cells were positioned inferiorly on the supraorbital ridge, superior to the occipital protuberances and the auditory canal of the ear. A guide screw located alongside the sensor mount ensured each sensor remained level and preventing any angular misalignment (Guo et al., 2020). This was done to prevent any cosine error affecting the measurement accuracy. If there were any angular misalignments causing cosine error during the measurements in this study, it would result in inaccurate and invalid neck strength readings. Load cells were also calibrated before neck strength testing.

The INSTA was then adjusted to the specific participant based on torso and limb length prior to the participant being securely strapped to the rig to limit external factors affecting the neck strength assessment. Each participant's INSTA measurements were taken after the first test of the season. These measurements for the position of each sensor, the chest and knees were kept the same throughout the season. The positioning of each component of the INSTA ensured that the participant's head was neutral, they had a flat back and that their knees were at a 90^0 angle to the hips.

Figure 3-2: INSTA set up with participant strapped in for testing.

3.2.2. Neck Strength Testing Protocols

Neck strength testing on the whole study population was conducted at least one week post the last match. For those in the front five sub-sample, testing took place three days post every match (with the exception of three testing weeks which followed rest weeks). To maximise the reliability and generalisability of the findings, the number of days post-match, time of day and researcher taking the measures were all kept the same, where possible. Individuals that were tested were not always part of the playing squad, however, all were currently involved in training at the time of testing. Data collection occurred in the team barn, which was well ventilated, on a 3G AstroTurf surface. All participants in the present study had previously participated in a neck strength training intervention in the 2020-2021 season and were therefore well familiarised with the testing and training protocols.

Before data collection, the participants completed a 5–10-minute warmup that was previously used by Williams et al., (2021). This consisted of dynamic aerobic exercise on an ergometer, followed by muscle activation activities to prepare the relevant musculature for a maximal contraction. Specifically, using a rowing ergometer, a two-minute row was completed at 24 strokes per minute, split into 30 seconds using only the arms, followed by 30 seconds using the back and the arms, and finally, a one-minute full body row. Following this, the participant completed ten shoulder shrugs and ten arm circles in any direction. Finally, the participant completed neck activation holds involving a chin-tuck isometric protraction for five seconds before relaxing. This was completed three times for each of the flexors, extensors, and lateral flexors.

Following completion of the warm-up, participants were strapped into the INSTA as described above. They were asked to perform a 50% voluntary contraction in of the tested each directions to further prepare the muscles for the MVC. Once the participant confirmed they were ready, the one rep max tests were conducted for each direction, in a random order. Each MVC was performed for three to six seconds. If the participant had clearly hit their maximum and was fatiguing, they were told to relax earlier. This was evidenced by a sustained decline in force for over a second. Peak force was recorded in Newtons (N) using Hauch and Bach DOP4 software (Lynge, Denmark). Following each contraction, the participant rested for a period of 30 seconds to enable recovery prior to a subsequent effort. This rest was based on previous studies with rest periods of 30 seconds or less being used in the following (Barrett et al., 2015; Geary, Green, & Delahunt, 2014; Hamilton et al., 2014; Maconi et al., 2016; Naish, Burnett, Burrows, Andrews, & Appleby, 2013).

During each MVC, motivational strategies were used to help maximise the participant's performance. Competitive and positive reinforcement was implemented as previous research has shown this to have positive impacts on scores (Theodorakis et al., 2000). This was kept the same for each participant so not to show bias to any individuals.

3.3. Additional Measurements

Injury data for the front five players were routinely collected by the team and subsequently accessed by the researchers. They recorded injury data on a weekly basis throughout the season, including injury type, date of the injury and the date of return to play.

Prior to neck strength testing, participants were asked three yes/no questions prior to each testing session. The questionnaire responses were collected to provide contextual information about the participant on the day of testing, however, the results were not directly used in the analysis of the project. Consequently, the validity of self-reported data may be subject to limitations. The response to the following questions were collated in lab notes during each session:

1. Are you experiencing any neck pain or soreness?
2. Do you have any current injuries?
3. Are there any other problems which could affect your neck strength?

Minutes played were collected for each participant throughout the season from club or sports websites. Specifically, following each game, the researcher recorded the minutes played according to these sites and subsequently used these to analyse the effect of playing time on neck strength. Other additional game events were collected through Opta program (Stats Perform, United Kingdom) for each player. Events were carries, tackles and scrums (definitions Table 3-1 (World Rugby, 2023)).

Table 3-2: Definitions of game events (World Rugby, 2023)

Game Event	Definition
Carry/Carrier	A player touching the ball who engages in contact with the opposition.
Tackle/Tackler	The defender who has attempted and succeeded in making a tackle and as a result has gone to ground.
Scrum	The scrum is used to restart play usually after a knock-on or forward pass. The forwards from each side bind together and then the two packs come together to allow the scrumhalf with the feed to deliver the ball to the scrum.

3.4. Statistical Analyses

3.4.1. Pre-, Mid-, Post-Season Study

Descriptive statistics were completed in Microsoft Excel® (Microsoft Corporation 2019), with more complex statistical analyses completed using Statistical Package for the Social Sciences, version 28.0 (SPSS) (IBM Corp., Armonk, N.Y., USA). Significance was set at $p<0.05$ and all data are reported as mean ± standard deviation, unless stated otherwise. Normality was ascertained for all data using the Shapiro-Wilk test, with parametric and non-parametric tests subsequently used accordingly. To explore the influence of time (within) and player position (between) on neck strength, a mixed measures analysis of variance (ANOVAs) was used. If significant main effects were found, Bonferroni corrected post hoc tests were used to identify the location of these significant differences.

Average neck strength for flexors, extensors, lateral left, and right flexors was taken for the season and compared against each other. This was done for the full squad, backs, forwards, and each individual position. A one-way ANOVA was then used to assess any significance between directions. To assess the influence of anthropometrics on neck strength, a Pearson's correlation was used.

3.4.2. Front Five Case Study

Descriptive statistics were done for players in the front five case study (N=15). All analyses and graphs produced were done in Microsoft Excel® (Microsoft Corporation 2019). Graphs showing correlations between neck strength, minutes played, and game events were produced. All individuals included in the case study accrued game time during the study period. Other contextual information was collected where possible, however, due to the temporal constraints and situational factors (notably the Covid-19 pandemic) this was not always attainable. Notably, although not able to be collected as part of the study, it was reported by the team that no specific neck strengthening exercises were being completed as part of training.

Player profiles were also produced and include neck strength over the season, injuries, and neck strength radars. These were utilised by both the research team and the playing team for selection. The purpose of the player profiles was to provide meaningful data for a professional sports team and show the benefit of neck strength monitoring against other variables. Player profiles can be found in Appendix C.

4. Results

4.1. Participant Anthropometrics

For all players age (years), body mass (kg) and height (cm) (mean ± standard deviation) are shown in Table 4-1. Values for forwards, backs and front-five are given with the individual positional groups below. The body mass of forwards was significantly greater than backs (*p*<0.001). Forwards were also older and taller on average compared to backs but neither showed significance.

Table 4-1: Age (years), body mass (kg) and height (cm) (average ± standard deviation) for all participants; all players, forwards (of which front 5), backs, then tight head prop (THP), loosehead prop (LHP), hooker, second row (SR), back row (BR), half backs (HB), centres and back three (B3)

	Population (n)	Age (years)	Height (cm)	Body Mass (kg)
All Players	33	25.0 ± 3.6	184.9 ± 7.4	103.1 ± 6.9
Forwards	20	25.9 ± 3.9	187.1 ± 7.3	112.1 ± 6.9 **
(Front Five)	*15*	*25.9 ± 3.5*	*186.1 ± 7.9*	*114.4 ± 6.3)*
THP	4	26.3 ± 3.6	180.3 ± 5.4	119.0 ± 3.4
LHP	5	28.4 ± 3.3	184.6 ± 1.1	117.4 ± 3.7
Hooker	3	25.3 ± 0.6	182.3 ± 3.5	104.3 ± 2.3
SR	3	23.7 ± 3.8	200.0 ± 1.7	113.2 ± 2.8
BR	5	25.6 ± 5.4	190.2 ± 3.8	105.2 ± 3.1
HB	4	24.0 ± 3.4	180.3 ± 9.8	85.0 ± 8.0
Centres	4	24.8 ± 2.6	184.3 ± 5.4	95.3 ± 9.5
B3	5	23.2 ± 3.3	180.4 ± 4.3	88.2 ± 3.3

4.2. Neck Strength of Full Squad: Pre, Mid and Post-Season

Table 4-2: The full squad MVC values for each position, for the three time points pre-season, mid-season and post-season. THP – Tight head props, LHP – Loose head props, SR – Second rows, BR – Back rows, HB – Half backs, B3 – Back three.

	Extensors (N)			**Flexors (N)**			**Left Flexors (N)**			**Right Flexors (N)**		
	Pre	**Mid**	**Post**	**Pre**	**Mid**	**Post**	**Pre**	**Mid**	**Post**	**Pre**	**Mid**	**Post**
All	291 ± 81	282 ± 75	266 ± 74	332 ± 96	308 ± 79	291 ± 52	238 ± 59	219 ± 57	193 ± 43	242 ± 70	227 ± 62	200 ± 47
Forwards	322 ± 89	310 ± 81	280 ± 88	369 ± 101	333 ± 89	306 ± 59	264 ± 57	236 ± 58	201 ± 49	263 ± 76	237 ± 722	211 ± 52
Backs	209 ± 41	210 ± 37	184 ± 43	198 ± 53	193 ± 39	181 ± 29	276 ± 35	269 ± 45	269 ± 29	244 ± 46	239 ± 41	245 ± 32
THP	428 ± 77	394 ± 66	352 ± 83	435 ± 120	430 ± 130	345 ± 69	277 ± 38	265 ± 49	209 ± 43	283 ± 45	245 ± 47	225 ± 71
LHP	340 ± 70	348 ± 87	333 ± 103	397 ± 94	330 ± 49	331 ± 42	277 ± 60	252 ± 49	238 ± 53	275 ± 85	258 ± 78	244 ± 47
Hooker	335 ± 34	306 ± 22	338 ± 53	437 ± 69	360 ± 58	383 ± 26	309 ± 41	293 ± 46	217 ± 36	318 ± 20	303 ± 36	243 ± 31
SR	268 ± 59	251 ± 53	248 ± 70	315 ± 59	287 ± 71	286 ± 43	259 ± 55	214 ± 32	220 ± 41	272 ± 100	222 ± 98	218 ± 44
BR	255 ± 53	251 ± 38	234 ± 60	266 ± 48	265 ± 13	244 ± 43	225 ± 63	179 ± 40	178 ± 63	220 ± 94	199 ± 65	179 ± 47
HB	282 ± 33	240 ± 27	260 ± 59	310 ± 41	282 ± 42	262 ± 18	220 ± 13	198 ± 61	196 ± 34	231 ± 57	214 ± 35	186 ± 8
Centres	203 ± 24	213 ± 52	232 ± 35	280 ± 79	263 ± 56	274 ± 46	181 ± 26	183 ± 16	177 ± 28	204 ± 37	187 ± 25	199 ± 47
B3	246 ± 26	261 ± 14	244 ± 41	246 ± 18	262 ± 26	271 ± 26	193 ± 47	196 ± 55	174 ± 29	196 ± 47	225 ± 54	170 ± 31

4.2.1. Backs vs Forwards at Pre, Mid and Post-Season

The full squad MVC values for each position, for the three time points pre-season, mid-season and post-season are given in Table 4-2. Forwards were significantly stronger than backs in all tested muscle groups at pre-season (extensors, p=0.002; flexors, p=0.002; left flexors, p<0.001; right flexors, p=0.016), and significantly stronger in all muscle groups other than right flexors at mid-season (extensors, p=0.002; flexors, p=0.008; left flexors, p=0.002; right flexors, p=0.175). At post-season, however, forwards were only significantly stronger in the flexors (p 0.002). Although they were stronger on average in all muscle groups, no other significant differences were present. The percentage differences between backs and forwards are presented in Table 4-3 below.

*Table 4-3: Percentage difference in neck MVC between backs and forwards at pre-, mid-, and post-season. *denotes significance of (p<0.05), **denotes significance of (p<0.01), *** denotes significance of (p<0.001).*

	% Difference in MVC			
	Extensors	**Flexors**	**Left Flexors**	**Right Flexors**
Pre-Season	-24.39**	-25.03**	-25.10***	-20.54*
Mid-Season	-22.85**	-19.40**	-18.44**	-11.50
Post-Season	-12.38	-11.99**	-9.78	-12.73

4.2.2. Positional Comparisons at Pre, Mid and Post-Season

Irrespective of time points, tight heads were stronger than all other positions in the extensors whilst also possessing the greatest flexor results at pre- and mid-season. At post-season hookers had the strongest flexors. For both the left and right flexors, hookers demonstrated the greatest values at pre- and mid-season, while loose head props were the strongest at post-season in both these muscle groups. Centres, back three players and back row players showed the weakest neck MVC over the season. There was not a consistent weakest position over time points other than in the neck extensors where centres demonstrated lowest values. This is shown in Table 4-2.

4.3. Changes in Neck MVC Across One Playing Season

The average neck MVC of the whole squad showed a decreasing trend in all directions over the season with a significant time effect seen across the season in all directions. Specifically, significant decreases were observed between pre-season and post-season for flexors (p=0.002), left flexors (p<0.001) and right flexors (p<0.001) but not for the extensors (p=0.081) (Figure 4-1). No significant differences were observed between pre- and mid-season (Flexors p=0.068, Extensors p=0.604, Left p=0.125, Right p=0.415). Between mid and post season, the only significant decreases were found between left (p=0.005) and right flexors (p=0.010).

For forwards players only, an ANOVA test showed significant change between the three time points in all direction (Figure 4-2) (Flexors p<0.001, Extensors p=0.007, Left p<0.001, Right p<0.001). Bonferroni post hoc tests showed a significant decrease between pre- and post-season in all directions (Flexors p<0.001, Extensors p=0.029, Left p<0.001, Right p<0.001) and between mid- and post-season for left flexors only (p=0.010). No other significant differences were observed. In addition, all significant results showed percentage differences that surpassed the CV (Pre- and Post-season, Flexors – 15.09%, Extensors – 20.58%, Left – 31.19%, Right – 24.93%. Mid- and Post-season, Left – 17.46%). No other changes across the season met the threshold. Among the backs players, no significant time effect was seen in neck MVC between any time points in any direction. There was also no percentage change within the backs that was greater that the CV.

4.3.1. Effect of Individual Position

When comparing individual playing positions over the course of the season, similar decreasing trends were also present (Table 4-2). Apart from centres and back three players, all other positions decreased on average over the season. Centres and back three players either increased or maintained neck MVC over the season. Furthermore, there were significant changes seen in tight head props extensor values between pre- and post-season and in back row players left flexor values between pre- and post-season.

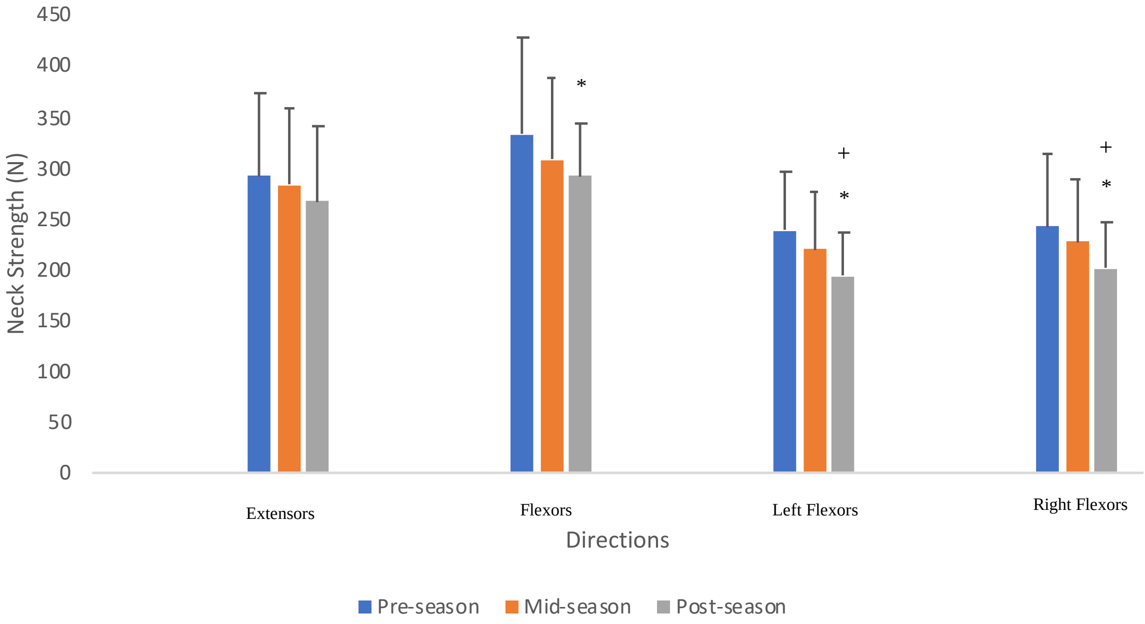

*Figure 4-1: Average neck MVC of the full squad at each time point in all directions. * - significance compared to pre-season. + - significance compared to mid-season.*

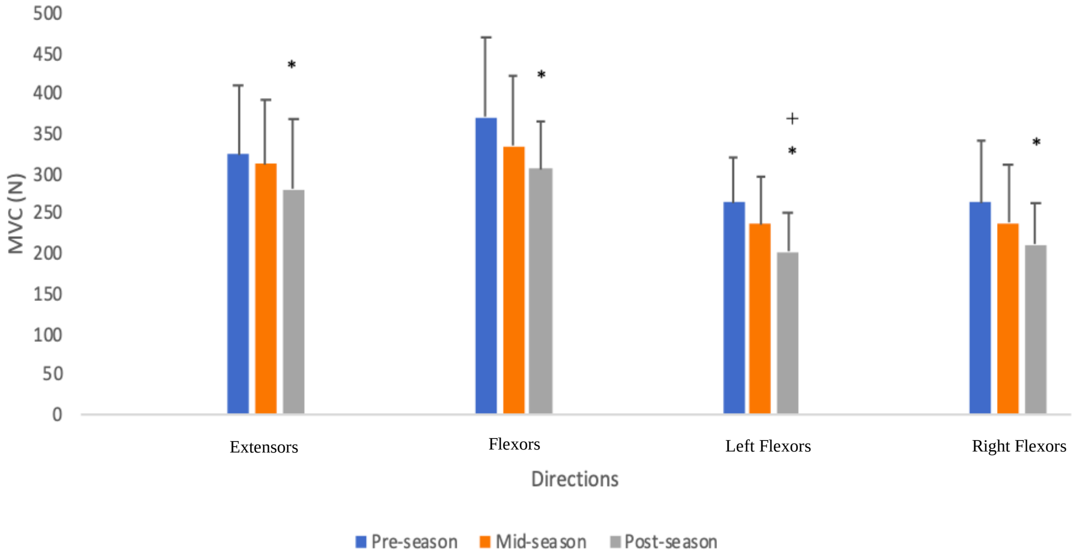

*Figure 4-2: Average neck MVC (N) in all directions at pre-, mid-, and post-season for forwards. * - significance compared to pre-season. + - significance compared to mid-season.*

4.4. Comparison of Neck MVC by Direction

For the whole squad across the season, Table 4-4 shows that the neck flexors and extensors demonstrated significantly higher values than left or right flexors, which were comparable to each other. Furthermore, although it failed to reach significance, there was a trend for the flexors to be higher than the extensors in the current players. The same was also evident for playing position with the flexors demonstrating the highest values, followed by the extensors, and left and right flexors being comparable. Apart from tight heads, second rows and back rows, all positions showed significantly higher values in the flexors than lateral flexors. Extensors were only significantly greater than lateral flexors in back three players.

Normalised neck strength data to body mass found the backs to be stronger than forwards in all muscle groups other than the flexors where there was no difference. Amongst the full squad, the same pattern regarding the strongest muscle groups was seen as in the non-normalised data.

Table 4-4: Neck MVC over the whole season by direction

	Neck MVC (Mean ± SD)			
	Extensors	**Flexors**	**Left Flexors**	**Right Flexors**
Full Squad	280 ±71	310 ±70	218 ± 46	224 ± 52
Full Squad Normalised (N/kg)	2.7±0.6	3.0±0.6	2.1±0.4	2.2±0.5
Backs	243 ± 31	271 ± 35	191 ± 29	201 ± 21
Forwards	304 ± 79	334 ± 77	234 ± 47	237 ± 61
Backs Normalised (N/kg)	2.8±0.5	3.0±0.5	2.2±0.5	2.3±0.3
Forwards Normalised (N/kg)	2.7±0.7	3.0+0.7	2.1±0.4	2.1±0.6
Loose head	336 ± 81	350 ± 50	253 ± 43	259 ±59
Tight head	379 ± 71	402 ± 100	247 ± 28	251 ± 54
Hooker	321 ± 34	381 ± 41	274 ± 25	282 ± 17
Second row	229 ± 64	309 ± 61	210 ± 38	201 ± 67
Back row	247 ± 39	258 ± 30	194 ± 53	199 ± 66
Half back	260 ± 32	285 ± 27	204 ± 28	210 ± 22
Centre	216 ± 23	272 ± 59	180 ± 11	197 ± 21
Back 3	251 ± 24	260 ± 12	188 ± 39	197 ± 24

4.5. Height, Body Mass, and Neck MVC Correlations

Table 4-1 above shows the average height and body mass for the participants in this study. These were used to assess if neck strength correlated with these anthropometric measures. Table 4-5 shows that body mass was significantly, positively correlated to neck MVC in all direction. There was no significant correlation between height and neck MVC.

Table 4-5: Correlations between neck MVC, height, and mass

	Body Mass		Height	
	p	**Correlation**	***p***	**Correlation**
Flexors	0.002	0.478	0.117	-0.213
Extensors	0.004	0.449	0.086	-0.244
Left Flexors	0.015	0.378	0.068	-0.265
Right Flexors	0.028	0.337	0.114	-0.215

4.6. Game Events

Data were gathered for the entire team for the number of carries, tackles, and scrums per game. However, since backs do not take part in scrums, these data were only relevant to forwards. For each game, the data was collated from players who had played the full 80-minutes, resulting in a sample of 74 data points for backs and 59 data points for forwards. Over the season, forwards made significantly more tackles than backs (p<0.001), but there were no significant differences in the number of carries.

4.7. Descriptive Front Five Case Study

Neck MVC was tested for the front five player group over 18 weeks during the 2021-22 season. This monitoring protocol was conducted to record changes in neck MVC week to week. The aim was to ascertain whether changes in either overall neck MVC or directional deficits could indicate a player's readiness to participate in competitive fixtures. Where available, these data were correlated with game events and injury records provided by the club. Injury data was collected directly from the club as alternative sources were not available. Therefore, the information provided was assumed accurate for the purpose of the study. No training data was available from the club, so no correlations were made with training data. As all individuals were part of the first team squad, it had to be assumed that they were undertaking similar training loads. The lack of training data limits the generalisability of findings in this study. However, given the unique circumstances that the data was collected in, the data was considered valuable.

In total, 16 front five players participated in the weekly neck monitoring. Due to player availability, the number of tests per player over the 16- week period ranged from 13 to four. This was attributed to the nature of a rugby season, individual schedules and reliance on the club to schedule players for testing, affecting consistent weekly tests.

Figure 6 shows all Front Five players neck MVC scores at every test they attended during the season. Over the season, 21 tests took place, however, due to several external factor players completed a varying number of tests within this period. Table 4-6 shows the number of tests each individual completed over the season, as well as the number of tests that occurred post-game.

Appendix D shows game data along with neck MVC data. Only post-game neck MVC data was included in the sample to correlate with the game data that preceded the test. The sample size for these correlations comprised of 59 data points. For all graphs the R-squared value (R^2) and gradient are shown.

Table 4-6: Test completions for the Front Five case study. The number of tests post game are also shown.

Player ID	Tests Completed	Tests Post Game
3	9	2
4	13	5
5	10	6
6	10	7
7	6	0
9	11	6
10	11	5
11	10	4
12	5	2
14	4	3
15	9	5
16	11	7
17	8	3
18	6	2
19	5	3

4.7.1. Front Five Neck MVC Tests

All front five neck MVC tests over the season are shown in Figure 4-3 with the average taken over the season for this group. Over the duration of the season, the majority of players neck MVC decreased on average from pre- to post-season. This is highlighted by the trend seen in the figure. Figure 4-3 also highlights the variation within the front five cohort, with several individual players demonstrating large spikes that reflect weekly fluctuations. The number of players attending each of the neck MVC test also has an impact on the week-by-week average contributing to the variation in the average. As a result, the R^2 values for all directions were found to be below 0.5, with the lowest values observed for the flexors and extensors.

4.7.2. Neck MVC and Game Events

Game data prior to each participant's neck MVC test was collected. Neck MVC data was collected two days post-game. Appendix D shows game events correlated to neck MVC data. Between the majority of events and neck MVC results there was a decreasing trend in MVC as the events increased. The only exception was an increasing trend between MVC score and the number of carries. Though these trends were present, none were significant.

4.7.3. Neck MVC and Injuries

Appendix C contains player profiles that comprise of information on neck MVC, and injuries provided by the club. Notably, there was considerable variation in the neck MVC data following injuries. Whilst some players demonstrated improvements in neck MVC post injury, others did not. It is plausible that individual differences in recovery and rehabilitation approaches could have influenced this. Unfortunately, these data were not available for this study, which makes it challenging to draw any conclusions about these data due to the fluctuations and differences in each circumstance.

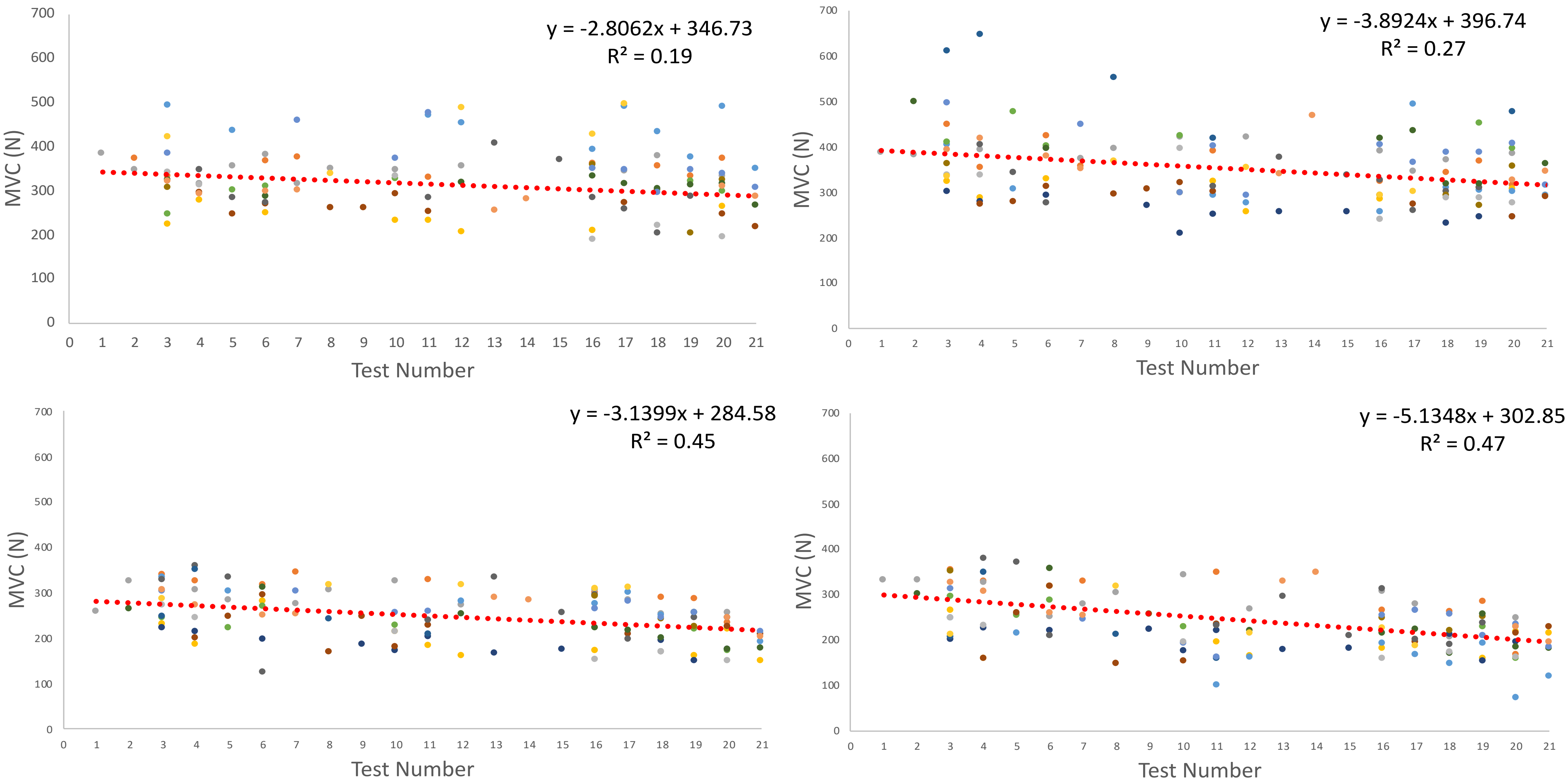

Figure 4-3: All front five players Neck MVC across the season. A- Extensors, B- Flexors, C- Left Flexors, D- Right Flexors

5. Discussion and Conclusions

The primary objective of this study was to examine the neck strength of an elite professional men's rugby team throughout a playing season, without implementing interventions, to observe the impact of a full season of play. Players were tested pre-, mid-, and post-season to assess these changes and analyse positional differences as well as seasonal patterns. A second aim of this study was to test front five players weekly. This testing was completed as part of a screening protocol with the objectives being to associate in-game events and injuries with fluctuations in neck strength.

Throughout this study, a consistent underlying focus was placed on developing a reliable screening method for neck strength testing, using a reliable testing apparatus. Despite the INSTA compromising on ecological validity due to the different neck profile seen compared to a normal neck profile, this study demonstrated its ability to produce highly repeatable data. Currently, there is no universally accepted testing equipment or method for assessing neck strength (McBride et al., 2023). As a result, this study introduces a methodology that has demonstrated the ability to yield consistent neck strength measurements and generate meaningful data for professional rugby teams. Importantly, this study was conducted in an operational, professional rugby setting, further enhancing its relevance and applicability. Further research is now needed using this methodology to validate this apparatus in larger cohorts and when accounting for a larger number of contributary factors, both of which were not possible on the current study.

5.1. Pre-Mid and Post Season Neck Strength

5.1.1. Description of Neck Strength Results Across the Season

The primary finding if this study was the significant decrements in neck strength seen over the duration of the rugby playing season in rugby union forwards. In contrast, the backs showed no significant changes in neck strength over the season but notably, there was a non-significant average increase in neck extensor strength for this group. These observed differences in neck strength can be attributed to the substantial differences in physical requirements between playing positions. The overall decrease in neck strength over the season seen in forwards players reflects the high levels of axial loading reported by Cazzola, Preatoni, Stokes, England, & Trewartha, (2015) and high levels of eccentric, isometric, and concentric strength qualities required during each individual scrummage. While the backs participate in a more comparable number of tackles and carries, they do not experience the same axial loading stress on the neck as forwards do during scrums. It can be hypothesised that the physical demands of playing rugby alone may be sufficient to stimulate an increase in neck strength among the backs, or at the very least, enough to prevent a significant decrease in strength. Positional differences in neck strength will be discussed further in 5.2.5.

5.1.2. Pre-Season Neck Strength

The results of the pre-season test indicated that forwards and backs displayed their greatest levels of neck strength in this period. This is consistent with the idea that pre-season training is predominantly focused on fitness and strength, with limited tactical and technical sessions involved (Mills et al., 2019). During pre-season, players are pushed beyond the requirements of a rugby union match to ensure they have the necessary endurance to play for the full duration of a game. This phase of training is crucial in building up fitness levels with neck strength also being an important area of focus. The late pre-season phase focuses more on rugby-specific training and on-field conditioning to prepare players for the upcoming season (Mills et al., 2019). During the playing phase of the season, skill-based and technical work are prioritised alongside maintaining the fitness levels achieved during pre-season (Mills et al., 2019). It is important to note here that players completed the pre-season testing at the end of their pre-season training block in this study. A comparison between the start and end of pre-season, while not logistically feasible for this thesis, would have provided further information regarding the specific conditioning undertaken during this period, designed to fortify players against injury going into matches.

Prior to pre-season training beginning, players are also well rested after the off-season. This is a key phase of recovery for players, but has also been shown to be detrimental to fitness levels and body composition due to the decrease in training stimuli (Clemente et al., 2021). Therefore, the trainings done during pre-season must prepare the player for the upcoming playing season. A previous study has found that implementing a pre-season intervention programme has improved neck strength over an eight-week period (Attwood et al., 2022). Some of this improvement may have been seen due to the low base line neck strength at the beginning of pre-season due to the off-season break, thus exaggerating the benefits of a pre-season intervention. There is therefore a gap in research measuring between post-season and throughout a pre-season training block.

5.1.3. Playing Season Neck Strength

For the forwards there was a decrease in neck strength from pre- to mid-season, and again from mid- to post-season. This suggests that the demands place on players during the season, combined with less time for recovery and specific neck strength training, resulted in decreased neck strength. This study included players who were involved in numerous matches, some of whom were also involved in international matches, further decreasing recovery times. Additionally, neck strength training was largely left down to the individual player, with no specific training plan in place during the season. Compared to other muscle groups, it could be said that neck strength was somewhat neglected which may have contributed to the observed decreases over the season.

As the season progresses, it has been found that players neck strength has decreased. Studies have also shown that injury rates increase as the season progresses (Cosgrave & Williams, 2019), likely due to increased fatigue in the later stages of a season (Aben et al., 2022). It is however unknown if decreased neck strength could have an effect on these injury rates and increased head injuries. Increased neck strength has been shown to reduce the risk of head accelerations (Caccese et al., 2018; Chavarro-Nieto et al., 2021; Dempsey et al., 2015; Dezman et al., 2013; Elliott et al., 2021; Peek et al., 2020; Salmon et al., 2018). There could therefore be an increased risk of head accelerations as neck strength decreases. The increased injuries in the later stages of the season found by Cosgrave & Williams, (2019) are likely a result of cumulative fatigue (Edwards, 2018) . The same trend across a season has been found in brain injuries. Cosgrave & Williams, (2019) found that match concussions (in Northern Hemisphere rugby) increased from 15 concussions/1000 player match hours in September to 35 concussions/1000 player match hours in May. A cause of these increases has been suggested as season-long fatigue. Cosgrave & Williams, (2019) suggested that fatigue could result in slower reaction times and increased technical errors contributing to this concussion increase. The findings in this study may be an addition to this theory as decreasing neck strength and the decreasing ability to activate the correct musculature to prevent head accelerations may be due to fatigue over the season.

Though this can be theorised, brain injury incidence was not recorded as part of this study. This was due to the data provided being limited, and the true incidence of brain injuries in this population could not be accurately established. Consequently, it is not known if the decreasing neck strength correlated to any increase in head or neck injury incidence. The suggestions from other findings mean it can be hypothesised, however further research should be done to understand if there is a link with decreasing neck strength over a rugby playing season and increased head injury.

5.1.4. Comparative Analysis

The decrease in neck strength in forwards players seen in this study over a season of rugby is comparable to other sports and muscle groups (Baker, 2001; Georgeson et al., 2012), however, there are limited studies testing neck strength over a season of rugby union. Of the existing studies, there is conflicting data on how neck strength changes over a rugby union season. Firstly, in rugby union Barrett et al., (2015), Naish, Burnett, Burrows, Andrews, & Appleby (2013), and Salmon, Sullivan, Handcock, Rehrer, & Niven (2018), all suggested that neck strength decreases or does not change over a season of rugby. This is the contradicted by the findings in this study. It is important to note however, the differences in testing apparatus and numerous environmental factors that can influence changes in neck strength. Particularly in Barrett et al., (2015) and Naish, Burnett, Burrows, Andrews, & Appleby, (2013) studies there were interventions in place which will have impacted neck strength results.

The only known observational study, Salmon et al., (2018), reported an increase in neck strength following rugby participation, suggesting that the hours of rugby played in the sample were sufficient to elicit cervical muscle strength adaptions. However, it is important to note that the participants in the previous study consisted of amateur players with infrequent playing schedules, whereas the current study focused on elite professional players. These individuals likely engaged in significantly higher weekly training volumes and had limited recovery time. The training that the participants in this study underwent include multiple gym and rugby training sessions during the week, and for forwards, multiple scrum sessions. All of the presented factors may have contributed to the differences in neck strength observed over the season compared to the previous study.

The study by Gillies et al., (2022) employed a different methodology to the current study. Rather than an observational study, Gillies et al., (2022) implemented a neck strengthening intervention during the season. For both forwards and backs, neck strength improvements exceeded the minimal detectable range, though not all improvements were significant. The changes in neck strength observed in the current study, which lacked a training intervention, differ to Gillies et al., (2022). The findings of both studies emphasise the potential of incorporating neck specific training strategies in professional rugby to mitigate against these decreases and maintain the overall profile of the neck during the season. Particularly, Gillies et al., (2022) highlighted the training programmes acceptability and feasibility within professional rugby.

In rugby league, over a 29-week season Baker, (2001) found a decrease in both upper and lower body strength, thus highlighting the impacts of a season. Georgeson, Weeks, McLellan, & Beck, (2012) also found decreases in lean muscle mass in rugby league players over a season. These authors suggested that this decrease in lean muscle mass contributed to a decrease in the number of strength training sessions performed as the season progressed. This reduction in strength training sessions could potentially lead to a decline in strength, endurance, speed, agility, and power throughout the course of a rugby league season. Relating back to the current study, this highlights how strength training during a season generally decreases as players are prioritising recovery prior to the next game. Therefore, with regards to overall muscle strength, the playing season can be viewed as a maintenance phase where the primary objective is for players to sustain strength gained during pre-season, whilst also avoiding excessive training that may impact on recovery. The emphasis is on preserving existing strength levels rather than focusing on improvements that could potentially hinder recovery.

5.1.5. Positional Differences in Neck Strength

Significant differences were observed between positional groups, with forwards showing a notable decrease in neck strength while backs did not. Potential reasonings for this have already been suggested, but an additional finding between these groups was that the difference between the backs and the forwards decreases as the season progressed. As shown in Table 4-3, the percentage difference between the backs and forwards average neck strength decreases from pre-season to mid-season, and again from mid-season to post-season; the only exception being between mid- and post-season in right flexors.

The disparities in the changes of neck strength throughout the season can be attributed to the different requirements of playing positions. Forwards, on average, engage in a higher number of tackles and are involved in scrums and mauls, whereas backs generally have less involvement in these activities. Specifically, during scrums, front row forwards necessitate substantial eccentric, isometric, and concentric strength in the extensor muscles of the neck (Mills et al., 2019). This is also highlighted by the significant decrease seen in extensor strength for tight head props in this study. During scrum events, these individuals experience high levels of axial loading and significant strain is put on the cervical spine (Cazzola et al., 2015; Posthumus, 2008a; Preatoni et al., 2013; Trewartha et al., 2015). Action has therefore been taken to decrease the initial engagement impact of the scrum though law changes. Current laws utilise a pre-binding action with the previous crouch-touch-pause-engage action did not. Cazzola et al., (2015) found this law change to reduce initial impact magnitude by up to 20%. Despite this, the significant impact of the scrum for the front row remains. Additionally, as these individuals continue to participate in matches and training sessions over the course of a season, the limited recovery time available for these muscles hinders their performance compared to the pre-season period. Consequently, a decline in neck strength during the season can be expected. In contrast, the reduced involvement of backs contact or scrum events suggests they will exert less strain on their neck muscles. Consequently, a diminishing gap between the two groups is present as the season progresses.

5.2. Directional Differences Neck Strength

In this study, across the entire squad, including backs, forwards, and individual positions, the strongest neck strength was found in the flexors, followed by extensors and then the lateral flexors. Among all groups, except for second row players, the right flexors exhibited greater strength compared to the left flexors. The testing direction was also randomised in this study so these differences cannot be attributed to a learning effect. These findings do not always consistently align with studies that conducted testing in both upright and prone positions. The current testing protocol tests the flexors with gravity, the extensors against and the lateral flexors perpendicular to gravity. This therefore does not show a normal neck profile as would be expected. However, all the neck strength tests during the season were completed under the same conditions and therefore the results within this study are comparable to each other (week-by-week). It is also important to note that the primary objective of the testing position employed in this study was not to directly replicate a rugby-specific position. Instead, its primary purpose was to limit the involvement of accessory muscles, consequently providing more repeatable data focused on the neck muscles. In contrast, other studies may prioritise examining rugby-specific outputs, and thus may be less concerned about the potential interference of other muscles in neck strength testing compromising on repeatability.

The observed findings, showing greater relative strength in flexion compared to other directions, differ from most existing research. Studies conducted by Liston, Leckey, Whale, & van Dyk, (2023), Salmon, Handcock, Sullivan, Rehrer, & Niven, (2015), Salmon et al., (2018) all reported higher extension values than flexion values when testing in a prone position. However, Williams et al., (2021), who's methodology has significant similarities to the current, demonstrated that in a male population, flexion exceeded extension. These discrepancies in results can be attributed to variations in the testing apparatus used. Despite all studies being conducted in a prone position, the methodology employed by Williams et al., (2021) involved the least utilisation of accessory muscles. In contrast, the apparatus used in the other studies involved the engagement of the arms and torso, thereby not isolating the neck or solely measuring neck strength. Isolation of the tested muscles has been shown to be a key consideration when testing for the standardisation of the test itself (Brown & Weir, 2001). This was considered important in the current study, despite potentially compromising on overall head and neck to torso measurements which could show how the entire body mass is connected (Babbs et al., 2001). Consequently, it is important to consider these differences in testing approaches and the potential influence of accessory muscle usage when interpreting and comparing the results obtained from different studies.

In addition, the study conducted by Liston et al., (2023) employed the VALD method, revealing absolute extension MVC ranged from 194 N to 744 N. The observed range of results demonstrates significant variability within this muscle group. However, it is important to consider the context in which these results are interpreted. The participants' ability to engage their arms and torso in force production may potentially provide an advantage in extension compared to flexion, leading to potential imbalances between the two directions. Furthermore, the prone position adopted by the participants limits the assistance from accessory musculature in flexion. As previously mentioned, it is crucial to interpret the results in the appropriate context, as certain methodologies may not exclusively assess neck strength but also incorporate other factors related to force production or muscle activation.

Though the findings differ to other studies, as part of a screening protocol, the results in the current study have been demonstrated as consistent and repeatable. Findings must always be interpreted with caution, considering the testing positions and methodologies used. However, when methodologies remain consistent, the results are comparable within the study.

5.2.1. Normalised neck results

Neck strength data normalised to body mass indicated that backs were stronger than forwards in all directions except flexors. This differs to the expectation in absolute values where many studies identify forwards as stronger than backs (Chavarro-Nieto et al., 2021). However, the majority of studies also do not present normalised values to body mass. One potential reason for only presenting absolute values is that if individuals exposed to the same magnitude of force, a greater neck strength, or neck ability may be required to withstand such force. Therefore, although backs were stronger in normalised results, their lower outright neck strength may leave individuals susceptible to being unable to resist higher magnitude forces accelerations (Caccese et al., 2018; Chavarro-Nieto et al., 2021; Dempsey et al., 2015; Dezman et al., 2013; Salmon et al., 2018).

5.3. Player Anthropometrics and Neck Strength

Forwards were generally older than backs, with props being the oldest positions (LHP 28.4 years and THP 26.3 years). Props' higher average age may be due to the skill and technique required for scrum performance, requiring more experience to reach an elite level (Gabbett, 2006). The age range aligns with previous studies on neck strength in rugby union (Black et al., 2018; Salmon, 2014).

In this thesis, the average height and body mass of forwards was significantly greater than that of the backs. In previous studies in elite men's rugby this is also consistent (Zabaloy et al., 2021). Previous studies have attributed the difference in weight between backs and forwards to position specific conditioning practices (Offman et al., 2016). Also, the specific demands of each position in rugby demand a certain body type for that position, particularly in the forwards (Till et al., 2017). The players that participated in this study are comparable by age, body mass and height to other elite, professional men's rugby union teams.

5.4. Front Five Case Study

The second phase of this study involved a case study of the front five players, specifically props, hookers, and second row players. Post-game testing was performed on these individuals as frequently as possible throughout the season. The frequency of testing for each player was determined based on various factors, including their previous game participation, availability for testing, and scheduling logistics within the sport science team. Consequently, the number of tests conducted per player ranged from four to twelve over the duration of the season. The collected data was also shared with the team to assist in their decision-making process when selecting the playing squad on a weekly basis. Despite the limited nature of these data and inconsistencies regarding testing, data was included in the study as it highlighted weekly variations in neck strength. The cohort, although small in numbers, was a professional rugby team. Few studies have the ability to present data on this cohort and therefore this was seen as presenting unique information for this group.

5.4.1. Main Findings

In addition to the overall decrease in neck strength throughout the season, there was an inverse trend between neck strength and game events, except for the extensors when compared to carries. Although this trend did not reach statistical significance, it is important to acknowledge the observed decrease, and future studies with larger sample sizes could further investigate. While acknowledging the limited sample size of this study, it is crucial to consider that the research was conducted within a professional setting with an elite rugby team, rather than in a sport science laboratory. Consequently, increasing the sample size for this study was not possible. However, the findings among the front five players highlight the need for increased funding and further research exploring the effects game events can have on neck strength. By conducting future studies with larger sample sizes, a more comprehensive understanding of these observations can be achieved.

The player profiles (Appendix D) display the neck strength profiles of the individuals as well as the injuries sustained by each participant throughout the season. With regards to neck strength, no significant imbalances were observed on average for any individual over the course of the season. The F/E ratios, indicating the strength balance between the flexors and the extensors, was above 0.6 for all individuals in their average neck strength measurements. However, it is important to note the lack of a current method to assess lateral ratios. No study to date has assessed the ratios between the left and right flexors, or between either lateral flexors or the flexors/extensors. This limits the current understanding of an individual's overall head and neck stabilisation and their ability to mitigate head accelerations. Future studies should focus on investigating the mechanistic aspects of concussions in rugby and exploring strategies to mitigate specific head impact kinematics.

5.4.2. External Factors

Although a decreasing trend over multiple tests was present, when comparing week by week tests, there was substantial variability in results for numerous individuals. This variability highlights the numerous factors that can impact neck strength. When testing neck strength weekly, it is important to consider inter-individual variability in the results seen. The observed variations may reflect differences in training loads, recovery status, and other factors that influence neck strength in rugby players. Additionally, individual factors such as stiffness, soreness, motivation, and other wellness factors external to the training and playing environment could have influenced the outcomes. An awareness of these factors was noted prior to the study beginning; however, collection of these factors was not made possible for this study.

5.4.3. Neck Strength Monitoring Protocol

The weekly testing of the front five group and the full squad testing at intervals during the season should be considered by professional sports teams as a monitoring process. The testing of the front five proved to be a repeatable and reliable process when considering neck strength data. The main reason for this is the design of the INSTA. By restricting accessory muscle groups when testing neck strength, external variables that could affect neck strength are limited leading to repeatable results. The INSTA is designed to be highly repeatable meaning each weekly result was comparable to the next, and consequently the team in this study could use the results to aid in selection and training for the subsequent weeks.

Despite the potential advantages of monitoring neck strength for both player welfare and performance, professional rugby teams have not prioritised allocating funds or resources towards this. At the elite level, the primary focus remains on optimising performance, and since the neck muscles form a relatively small group with limited direct impact on performance compared to some other groups, teams tend to overlook its significance. As individuals fatigue over the duration of a season, there is an increased risk of injury (Cosgrave & Williams, 2019). This observation can also be applied to the neck. As the neck fatigues over the season, this risk of injury may increase highlighting the importance of monitoring protocols. Despite this, neck strength is just one component of the overall necks ability to stabilise the head. Improving this overall profile is likely more beneficial than targeting one facet such as neck strength. This improved profile includes, but is not limited to, the absence of imbalances, improved endurance and the ability to activate the neck muscles. Thus, the active monitoring of neck strength, and other factors, may help inform on training strategies.

5.5. Neck Strength Development

The findings presented in this study highlight a distinct requirement for ongoing neck training and development in elite rugby throughout the season. Neck strength has been recognised as a potential strategy to reduce head injuries (Chavarro-Nieto et al., 2021). However, effective implementation of these strategies requires further efforts, particularly in light of the observed decline in neck strength among forwards over the course of the season. To address this, it is recommended that future research and professional teams consider integrating proven neck training interventions. These interventions could be implemented at various time points, such as during pre-season training, throughout the season if feasible within team schedules, or during extended rest periods like international breaks. By incorporating these interventions, potential benefits include better preservation of neck strength during the later stages of the season, where decreases have been observed. Consequently, this approach may contribute to a reduction in head injuries and have a positive impact on player welfare.

It is essential for the entire squad to engage in overall neck development throughout the season, including the backs. While it may be perceived that backs do not require such training as they are not involved in scrums, it is important to consider several factors. Firstly, there is no significant difference in the number of carries performed by forwards and backs during matches. Therefore, both positions face a similar risk of collisions in the contact area. Secondly, previous research has demonstrated that increased neck strength can reduce head accelerations across all sports (Alsalaheen et al., 2019; Caccese et al., 2018; Chavarro-Nieto et al., 2021; Dempsey et al., 2015; Dezman et al., 2013; Elliott et al., 2021; Salmon et al., 2018; Viano et al., 2007). Consequently, to enhance the safety of all players, backs should also participate in these interventions for their own well-being.

Within the tested team, it could be suggested that despite the weekly testing, there was limited awareness among the coaching staff regarding the significance of neck strength training at the elite level of rugby. Possible reasons for this lack of training implementation may include the perception that the neck is comparatively small compared to other muscle groups. It may not be considered as important and may have limited effect on player performance compared to some more obvious muscle groups. Emphasis is also often placed on skills and general rugby training, which are seen as more crucial. Furthermore, the primary focus in professional rugby is generally performance based rather than prioritising player safety. Performance is the determinate of future funding and is the main drive in the direction of the club. This consequently leads to less emphasis on neck strength training and other training based on injury mitigation, as it may not directly enhance rugby performance.

The completion of neck training by elite players carries importance not only for the individuals and teams directly involved but also for the broader community game. Research has shown that success in elite sports can lead to a "spill over" effect, increasing participation in community sports (Mutter & Pawlowski, 2014). Though not always the case, it is plausible that this spillover effect may lead to young athletes emulating their heroes, and specifically their training methods. Therefore, the implementation of strategies at the elite level has the potential to trickle down to the community level, benefiting a wider range of athletes. Studies in elite players should also be replicated at younger ages and playing levels. Thus, best practices can be introduced as early on in an individual's career, and ideally, prior to their first concussion/injury. Research has also suggested that youth athletes can begin acquiring fundamental skills necessary for participation in complex sports between the ages of 10 and 12, and this age range may offer optimal learning opportunities (Brown et al., 2017; Nelson, 1991). Therefore, introducing neck strengthening strategies and other training methods, such as falling techniques, at this developmental stage may establish a foundation for enhanced success during adolescence. Additionally, once individuals reach the elite level it would one; be part of their training routine and two; they would have an underlying level of neck strength that would help to reduce the risk of head injuries. Despite this potential, rugby unions rarely promote neck strength training, whereas fitness and rugby skills training is readily available. If neck strength training strategies were available, players from a young age may begin implementing them.

5.6. Research in Professional Sports Teams

The front five case study was a descriptive, qualitative section, with the data presented using visual methods, as the sample size was too small to generate meaningful statistics. This thesis focused on one professional squad, so only 16 front five players were included in this analysis. This study provided actionable information regarding weaknesses and imbalances that can be addressed through strength and conditioning interventions or load management strategies. The omission of statistical analyses in this section may not satisfy academic convention, however, smaller descriptive studies such as this may provide a rich source data and actionable insights directly applicable to specific players. Future research should consider similar research combining multiple teams which could improve the generalisability and reliability of what has already been seen in this study.

5.7. Limitations

This study was carried out during the Covid-19 pandemic which presented complications to the data collection. Throughout the season, a total of six games were postponed due to

Covid-19 breakouts. Consequently, there was an 11-week period from October 25th to January 4th during which no data could be collected. During this timeframe, games were not played, and access to the team's environment was restricted to only individuals within the organisation in an effort to prevent Covid-19 outbreaks. Consequently, the availability of consistent, week-by-week data was limited during the first half of the season for this study. While the majority of league games postponed during this period were eventually rescheduled, the same cannot be said for cup games. As a result, certain post-game data could not be collected due to the cancellation of these rescheduled cup games.

The lockdown measures imposed during the study period prevented the inclusion of a female cohort in this research. Data collection from non-professional sports teams was limited during this period, making it unfeasible to incorporate a female sports team in the study. This was primarily due to the absence of professional female rugby teams in Wales at the time of data collection. Female players were also not granted the same dispensation as professional male players to continue training during the lockdown. Consequently, players had to rely on home-based training during this period. While the WRU introduced professional contracts for a small number of women's players in 2021, there was no agreement in place for these athletes to undergo testing with Swansea University during the study. As a result, the exclusion of female players represents a significant limitation in this research, particularly considering the observed differences in head impact biomechanics and neck strength between female and male university rugby players (Williams et al., 2021).

This study was conducted in collaboration with a professional rugby club, which meant that the organisation of testing, including who, where, and when to test, was under the control of the club staff. This arrangement posed challenges in obtaining contextual data in a consistent and reliable manner, necessary for drawing meaningful conclusions about the study findings. Therefore, the overall conclusions of the study also lack generalisability due to this partial data set. The study design aimed to assess players' neck strength after each game, which relied on scheduling all players who had participated in the game for the testing. While this was mostly achieved, logistical constraints arising from the team's schedule, such as mandatory meetings and other commitments, occasionally prevented some players from attending post-game testing. Additionally, variations in player selections, regular international breaks, and players attending national team camps, contributed to irregularities in testing the same players on consecutive weeks.

This study lacked control over player's behaviours, including their participation in additional training activities, throughout the season. While no specific interventions were implemented during the season, it was acknowledged that some players engaged in extra individual training, which could potentially influence the results. This information was reported to the researchers during the study. Consequently, although the study was conducted without interventions, it was not possible to measure the training load, and any additional training undertaken by the players remained unknown.

The study encountered challenges related to player motivation. Although motivation was not directly measured, it was evident through players' actions and resulting neck strength scores when their participation lacked sufficient motivation. Another issue arose from the lack of consequences for players who did not attend testing sessions. While it was arranged that all players who had played in the preceding weekend's games would be scheduled for neck strength testing, not all players consistently attended. Instances of players forgetting to attend resulted in data gaps following their participation in games. Measurements were taken at the beginning of the season to determine the positioning of the INSTAs. However, players frequently experienced slight discomfort and requested changes in the sensor placement. The occurrence of such requests was inconsistent, with some weeks necessitating adjustments while other weeks the setup remained satisfactory. These requests for changes in sensor positioning were usually due to knocks or injuries sustained by the players during games or training sessions. Consequently, player comfort played a crucial role in their neck testing performance. As a result, there were instances where the INSTA positioning varied among players from week to week, introducing potential variance in the results. It is important to note that if the players were not comfortable, there could be a larger variance in the results as they may not be able to perform at their maximum capacity.

The INSTA also produces a different neck profile to what may be considered 'normal'. This creates challenges when comparing data between studies. Additionally, due to the quadruped position that testing takes place in, the neck muscles are not all tested under the same external conditions. The flexors are tested with gravity, extensors against and lateral flexors perpendicular to gravity. This makes comparisons between directions more difficult and potentially leads to a sub-maximal extensor value. However, the results found here are comparable to other studies which test in the quadruped position (McBride et al., 2023; Salmon et al., 2018). Additionally, the testing position was kept consistent in the current study, which Krause et al., (2019) noted is important for comparing neck strength results and assessing changes over a period of time.

5.8. Future Directions

5.8.1. Practical Considerations for Future Research

Future interventions targeting neck strength during the season have the potential to play a vital role in maintaining neck strength during the latter stages of the season. This, in turn, may contribute to reducing head injuries by minimising head accelerations. Specifically, enhancing neck strength and stability could help intervene and reduce 'whiplash' type concussions and direct head to ground impacts through the improved ability for individuals to stabilise their head in mid-line. Notably, injuries, including brain injuries, have been observed to increase during this late phase of the season (Cosgrave & Williams, 2019). This gives opportunity to implement interventions aimed at mitigating these injury risks. Previous interventions, as demonstrated by Attwood et al. (2022) and Gillies et al. (2022), have shown success in improving neck strength. Leveraging this knowledge and incorporating such interventions during the season could be pivotal for future injury prevention measures. Subsequently, it is recommended that future studies evaluate the impact of a mid-season intervention or a season-long neck strength program in a professional rugby team to assess its effect on neck strength. Despite this, neck strength is only one facet that could assist in reducing head injury risk. Further research into properties outside on isometric neck strength need to be included in studies to gain a more comprehensive understanding of the neck and its role in reducing head injury.

Although it was not feasible to conduct a direct comparison between the start and end of the pre-season in this thesis, such an analysis would have provided valuable insights. Future studies should consider this as it can inform on and assess specific conditioning protocols implemented during this period to enhance players' resilience against injuries during matches. Though previous studies have conducted investigations during the pre-season period they often incorporating neck strength interventions aimed at improvement.

It is recommended that future studies focus on observing pre-season training to evaluate the efficacy of current methods employed, including those involving neck strength training. Such research can contribute to the identification of appropriate interventions for these phases, whether aiming to enhance existing approaches or implement training strategies from the outset.

It is important to consider the current research design's applicability to female and youth populations. While this study focused on monitoring the changes in neck strength throughout a season, recent research has highlighted substantial differences between males and females, as well as between youth and adolescents. These differences have been found in neck strength and head impact kinematics in a rugby population (Williams, Petrie, et al., 2021) and between elite, professional males, and other populations (Chavarro-Nieto et al., 2021). The research conducted in this study cannot be generalised to other populations. In future research designs, it is recommended to include a more diverse and balanced sample to address the existing gender data gap and prevent further disparities between males and females in research.

There is an opportunity to evaluate neck strength in conjunction with other relevant variables. While this study focused on correlating neck strength with match events, future investigations could explore additional direct and extraneous variables that may impact neck strength. These variables might encompass factors such as neck stiffness, soreness, cervical range of motion, proprioception, and more. Although it is challenging to assess all these variables in a single study, future research designs could aim to incorporate a broader range of variables to gain a deeper understanding of their effects on neck strength. It is also crucial to acknowledge that studies lacking the inclusion of all these variables may overlook numerous extraneous factors that can influence neck strength. Consequently, drawing conclusive findings becomes difficult if the complete picture is not presented.

With regards to the effect of matches, if possible, future research could consider testing pre- and post-match on the same day. The direct effects of a rugby match on neck strength has not yet been studied. The effects post-game could advise on players return to training following the games. If there were changes in neck strength post-game, players may need to return to within a percentage of their pre-season value before participating in scrum training/contact training. One objective that could not be answered in this study was if players were returning to scrum training too soon in the week post-game. This could be answered if studies were to test post-game throughout a season. If this was possible, it could better show the effects of match play than in this study. Testing three days post-match means there are several other variables in the days between the game that may also affect neck strength data. This, however, is dependent on the cooperation of professional sports teams.

5.8.2. Collaboration Between Researchers and Sporting Organisations

Future researchers should also be aware of the challenges faced when working with professional sports teams. Enhancing collaboration and building strong relationships between researchers and these teams should be a priority. Currently, researchers are often perceived as outsiders entering the sports team's environment and are not always accommodated for. This has the potential to affect the research outcomes, which ultimately aim to benefit those within the team as well as the researched population. Consequently, improved collaboration between professional clubs and researchers is essential, particularly regarding testing logistics and the sharing of data.

5.8.3. Neck Strength Testing Methods

The use of the equipment in this study offers advantages for future research. The assessment of neck strength was conducted in a unique and occasionally challenging environment, specifically regarding the transportation of the INSTA to and from testing locations. This flexibility in transportability is crucial for future studies, as it eliminates any limitations in conducting tests. Furthermore, the equipment allows testing to be conducted in diverse environments and on various surfaces due to its transportability and design. Specifically, in this study testing was performed on a 4G surface, which differs from the typical laboratory setting. Despite the highly unusual and unique surface used in this research, the data collected remained reliable and repeatable. Generally, research is commonly carried out on hard surfaces in laboratory settings, which is a more straightforward and convenient approach compared to the unconventional surface utilised in this study. This highlights the versatility of the INSTA, enabling its utilisation in various locations.

The standardisation of neck strength testing methods remains and important consideration for researchers. The INSTA has demonstrated reliable and repeatable testing by restricting the accessory muscle usage, however, there is no consensus on the optimal approach for measuring neck strength in rugby. Each different method provides advantages and limitations. The ability to isolate the neck musculature may be advantageous for evaluating neck strength, but in doing so, there may not be a true reading of the necks ability to stabilise the head in conjunction with the trunk. Additionally, this may reduce ecological validity by not fully simulating a sport-specific position or recruitment pattern. Conversely, alternative equipment may allow for more sport-specific assessment but could also introduce greater variability. The lack of standardisation makes cross-study comparisons challenging. Establishing consensus guidelines for neck strength measurement in rugby union would facilitate more meaningful comparisons and aid the understanding of the neck's role in rugby union.

5.9. Conclusions

This study has found a decline in neck strength among male professional forwards throughout the duration of a rugby season, whereas no significant change was found in the backs. This primary finding deviates from previous studies, as there is limited information available regarding neck strength changes over the playing season without interventions. The decrease in neck strength over a playing season in forwards players is a unique and actionable insight for this club. Due to the partial and limited nature of these data, however, further research is required to investigate this phenomenon in a larger and more diverse cohort to establish any generalisable trends. These future studies must be conducted with full collaboration and cooperation from team staff, as data collected by the club (training data, playing intensity, workload, injury reporting) is imperative to contextualise neck strength data and explain trends seen.

The front five cohort exhibited an overall decline in neck strength throughout the season, with notable variations observed in week-on-week testing. These findings underscore the importance of accounting for numerous extraneous variables when interpreting neck strength data. The generalisability of these findings, however, is limited due to the small dataset and the curtailed availability of players for each of the testing sessions. Additionally, small, non-significant correlations were observed between neck strength and game events, indicating game events do have some effect on neck strength. However, it also suggests the necessity for further research in this area with a larger sample size. The issue of concussions and head injuries has become a primary focus for World Rugby, given the diagnosis of early onset dementia in several former international players. Consequently, the need for mitigation strategies or law changes have been a key focus to make rugby safer for those who play. Maintaining neck strength can be suggested as one strategy for reducing head injuries and mitigating head accelerations, particularly in the later stages of the rugby season. Therefore, implementing proven interventions at the time points this study has identified decreases in neck strength, could serve as an additional approach to mitigate head injuries in rugby.

6. References:

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Appendices

Appendix A – Participant Consent Form and Information Sheet

PARTICIPANT CONSENT FORM
(Version 1.3, Date: 10/09/2019)

Project Title:
LOOK-A-HEAD to Health and Wellbeing in Sports
Contact Details:

Dr. Elisabeth Williams
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	Please initial
1. I confirm that I have read and understood the information sheet dated 26/03/2018 (version number 1.2) for the above study and have had the opportunity to ask questions.	
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.	
3. I understand that sections of any of data obtained may be looked at by responsible individuals from the Swansea University or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records.	
4. I agree to take part in the above study, to have a photographic image to be taken for educational and research purposes only and that in taking my photo the face image will be made opaque.	

_______________________________ _________________ ___________________________
Name of Person Taking Consent Date Signature

_______________________________ _________________ ___________________________
Name of Person Taking Consent Date Signature

_______________________________ _________________ ___________________________
Researcher Date Signature

PARTICIPANT INFORMATION SHEET
(Version 1.3, Date: 10/09/2019)

Project Title:
LOOK-A-HEAD to Health and Wellbeing in Rugby Union Swansea University ref: 2016-059

Contact Details:

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1. Invitation Paragraph

My name is Dr. Elisabeth Williams; I am a senior lecturer the Applied Sport, Technology, Exercise and Medicine (A-STEM) Research Centre in the College of Engineering at Swansea University. A-STEM is conducting a study called LOOK-A-HEAD to assess the effects of repeated head impacts on player health in Rugby Union and you are invited to participate.

2. What is the purpose of the study?

Rugby is the sport of choice for more many people in Wales. As with any contact sport, injuries are a common and expected feature within the game. At the senior and professional level of the game, concussion and serious injuries are particularly topical and regularly relayed in the media. All involved in this study take the safety of players at all levels seriously. A range of initiatives and programmes are in place to minimise serious (harm) injuries, however due to the nature of sport, particularly contact sport; injuries will occur from time to time. Player safety and welfare is paramount – we want to protect the health of athletes over the short and long term. We are not saying there is a problem or a definite link between rugby and long-term health issues. What we are doing is helping Welsh rugby organizations take steps to find out more via this research project. This is not just a matter for rugby but for all of sport.

3. Why have I been chosen?

You have been selected to participate in this research project as you are currently playing rugby union at a professional or elite level. Your participation in this research is voluntary. You are free to withdraw consent and discontinue participation at any time without influencing any present and/or future involvement with Swansea University. Your consent to participate in this research will be indicated by your signing and dating the consent form. Signing the consent form indicates that you have freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from Swansea University.

4. What will happen to me if I take part?

You may be asked to complete a pre-competition concussion history questionnaire, a sports concussion assessment baseline evaluation, undertake a measurement of your head and neck and to complete a number reading test. You will also be asked to perform some neck strength tests during preseason, several times during the season and at the end of the season. You will be asked to wear a custom-fit mouthguard which will contain accelerometer and gyroscope sensors during training and matches. To make your own mouthguard, you will be required to have a qualified dentist take impressions of your teeth. These will be used to make the guard for you. During the mouthguard development process, you may be asked by the research and development team for your feedback about how comfortable it is to wear. You may also be asked to specify particular features of your mouthguard which you would like altered to ensure it is comfortable. During preseason, you will be asked to provide a small (6 mL) blood sample and if you are highlighted to have had a head impact during the season, another small blood sample (0.5 or 6mL) will be collected every second day until the end of the return to play protocol.

5. What are the possible disadvantages of taking part?

Only those discomforts and risks that normally occur from participating in rugby union activities. This includes the risk of a sports-related concussion. This risk can be increased if you have had a previous concussion and this will be discussed with you as part of the concussion history assessment. You may be asked to see another health care professional for further assessment and clearance to play as part of this process. You may feel some slight discomfort with wearing the external patches. In the initial stages of mouthguard development, you may find this to be too large. You will not be asked to wear the mouthguard in either training sessions or games until you are completely satisfied it is comfortable for you.

6. What are the possible benefits of taking part?

Information gained from this research has potential to help shape training strategies, and develop prognostic indicators of value to athletes, clinicians, physical conditioners and coaches.

7. Will my taking part in the study be kept confidential?

The data from the research project will be coded and held anonymously in secure storage under the responsibility of the principal investigator of the study in accordance with the requirements of Swansea University. All reference to participants will be by code number only in terms of any research theses and publications. Identification information will be stored on a separate file and computer from that containing the actual data. Only the lead investigators will have access to computerized data. Should a situation occur where you become injured then your identified next-of-kin / legal guardian / parent that has been recorded and/or signed the consent form will be contacted to advise them of the injury, the care provided and where you have been transferred to. The information obtained will also be passed onto the healthcare service as part of the on-going management of your medical care.

8. What if I have any questions?

If you have any questions please feel free to contact Dr Elisabeth Williams or Dr Shane Heffernan. Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor – Dr Williams. Concerns regarding the conduct of the research should be notified to Dr Williams or Dr Heffernan. Please take the necessary time you need to consider the invitation to participate in this research. It is reiterated that your participation in this research is completely voluntary. If you require further information about the research topic please feel free to contact Elisabeth Williams (details are at the top of this information sheet). You may withdraw from the study at any time without any adverse consequences of any kind. You may ask for a copy of your results at any time and you have the option of requesting a report of the research outcomes at the completion of the study.

Appendix B – Technical Note: INSTA (E. M. P. Williams et al., 2021)

Appendix C – Front Five Player Profiles

Appendices B and C can be accessed through the following link: Appendices

Appendix D – Front Five Neck Strength and Game Events

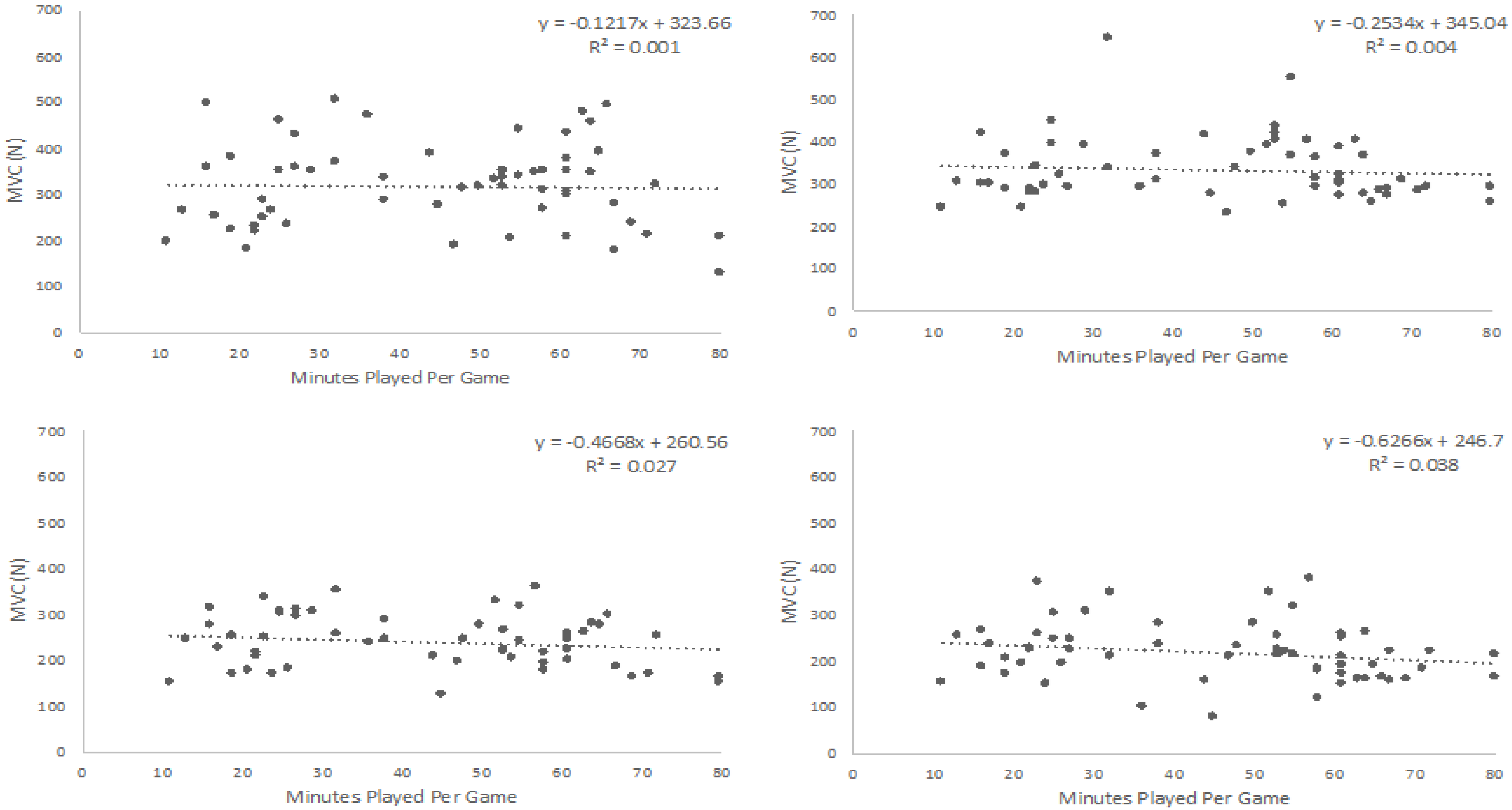

Figure E-1: All front five players neck strength compared to the number of minutes played prior to the test. A- Extensors, B- Flexors, C- Left Flexors, D- Right Flexors

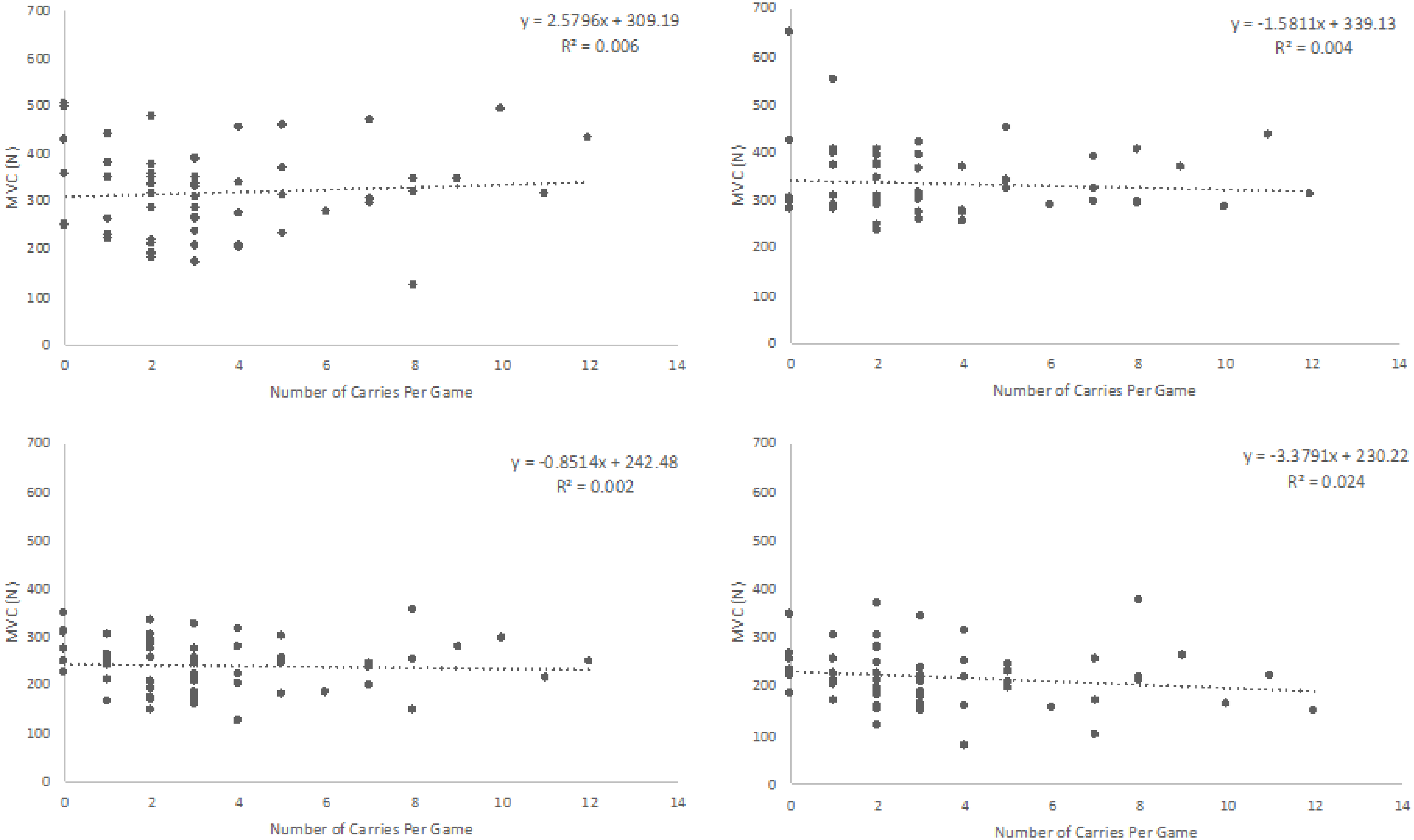

Figure E-2: All front five players neck strength compared to the number of carries made prior to the test. A- Extensors, B- Flexors, C- Left Flexors, D- Right Flexors

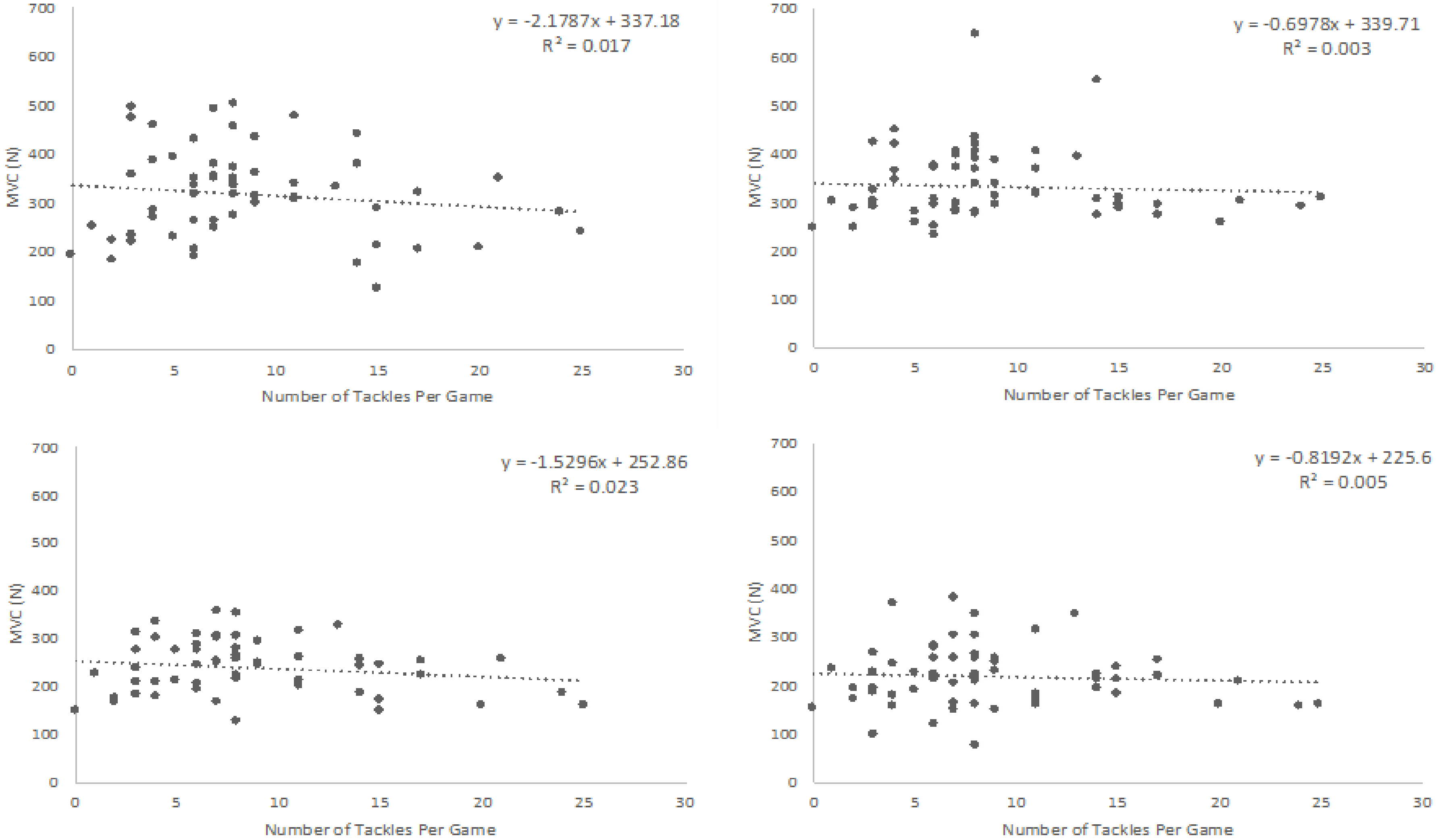

Figure E-3: All front five players neck strength compared to the number of tackles made prior to the test. A- Extensors, B- Flexors, C- Left Flexors, D- Right Flexors

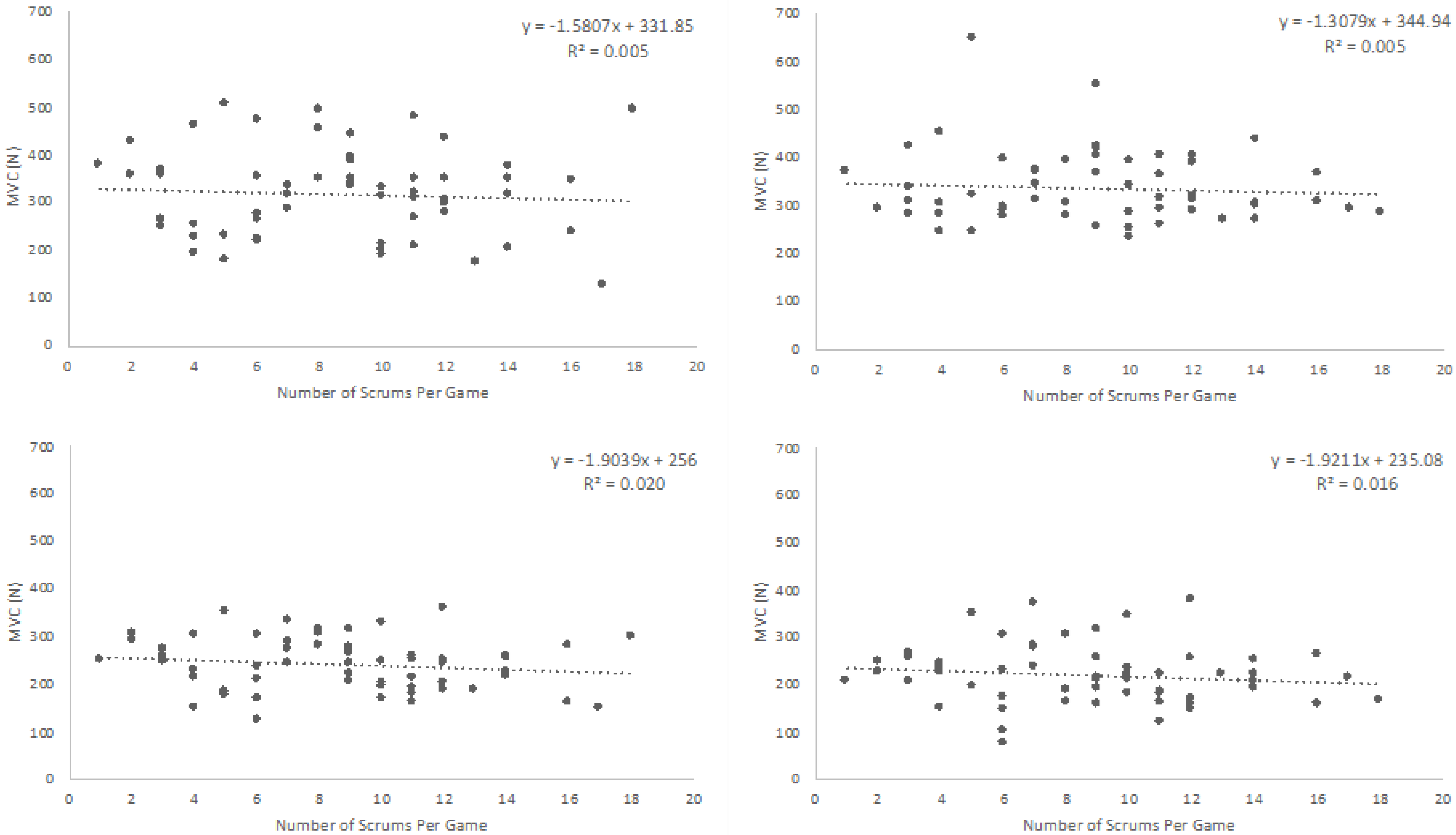

Figure E-4: All front five players neck strength compared to the number of scrums prior to the test. A- Extensors, B- Flexors, C- Left Flexors, D- Right Flexors

Description of Figures and Results

The figures above show the Front Five cohorts neck strength compared to the game events collected during this study. Data in these graphs is only included if a player completed a full 80 minutes. For the majority of event there was a small, decreasing trend in neck strength as the events increase. This however was not significant for any of the above. The only exception was an increasing trend between the number of carries and the extensors MVC as seen in Figure E-2. Though non-significant, tackles, scrums and minutes played have a small effect on neck strength. As this plays out over the course of a full rugby season, the observed decrease in neck strength among the Front Five cohort could potentially be influenced by these game events. An increased sample size and data from multiple teams over a full season may show a more comprehensive view of game events compared to neck strength. Additionally, future research should look to examine the cumulative impact of multiple game events on neck strength, as it is unlikely that a single event alone can account for the decreasing neck strength observed over the course of a rugby season.