COLLISION TRAINING PRESCRIPTION IN COLLISION SPORTS BY ELITE COACHES: A QUALITATIVE STUDY

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DECLARATION

I, Mr Mogamat Faeez Williams hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is submitted for another degree at this or any other university.

Signed by candidate

(Signature)

30.01.2023

(Date)

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AE	Athlete Exposure
CINAHL	Cumulative Index to Nursing and Allied Health Literature
DOMS	Delayed Onset Muscle Soreness
EFC	Extreme Fighting Championships
EIMD	Exercise-Induced Muscle Damage
ERIC	Education Resources Information Center
FMS	Functional Movement Screen
GPS	Global Positioning System
HIT	Head Impact Telemetry
HREC	Human Research Ethics Committee
IIMD	Impact-Induced Muscle Damage
N	Newtons
MADYMO	Mathematics Dynamic Models
MMA	Mixed Martial Arts
$m.s^{-1}$	Meters per Second
$m.s^{-2}$	Acceleration
PH	Player Hours
PRIMO	Peer-Reviewed Instructional Materials Online
RE-AIM	Reach, Effectiveness, Adoption, Implementation, and Maintenance
ROM	Range of Motion
RPC	Rate of Perceived Challenge
RPE	Rate of Perceived Exertion
TMA	Time Motion Analysis

LIST OF ABBREVIATIONS CONTINUED

Abbreviation	Definition
TRIPP	Translating Research into Injury Prevention Practice
UFC	Ultimate Fighting Championships
USA	United States of America

GLOSSARY OF TERMS

Term	Definition
Collision Sports	Sports that contain enormous collisions among athletes and the playing surface (Naughton et al., 2020).
Elite Coaches	Coaches participating at a national or international level, professional league, or university-level competition in their respective sports (Swann, Moran, & Piggott, 2015).
Exercise Prescription	Formulating personalised programmes based on exercise principles such as frequency (how often), intensity (how hard), time (duration or how long), type (mode or what kind), volume (amount), and progression (advancement), with consideration for the specificity of the individuals health status, function, and physical and social environment (American College of Sports Medicine, 2018).
Sports Coaching	Guiding, motivating, and training athletes in their preparation for a sporting event, or a sporting career (Nettles, 1992).
Collision	When athletes make contact or collide with one another or the ground with great force (Segen, 1992).
Collision Injury	An injury sustained by an athlete during collision sports training or matches because of (contact) force between other athletes or the playing surface (Naughton et al., 2020).
Grapple	In Judo and Jiu-Jitsu: gripping, throws, foot sweeps, clenching, joint locks, chokeholds, and ground grappling techniques (Ratamess, 2011). In rugby union: the post-tackle contact phase involves static muscle contractions to gain tackle dominance (Naughton et al., 2020).

GLOSSARY OF TERMS CONTINUED

Term	Definition
Live Collisions	Player-against-player(s) collisions, including tackling to the ground, full-speed blocking, and can occur with equipment (Krill, Borchers, Hoffman, Tatarski, & Hewett, 2017).
Perspectives	A particular attitude toward something; a way of thinking about something (Oxford University, 2023).
Tackle	The tackle event in rugby union is a technical and physical contest between the player in possession of the ball (known as ball carrier) and the opposing player attempting to regain possession of the ball (known as the tackler; Hendricks & Lambert, 2010).

ABSTRACT

Background

Collision training is essential for coaches to prepare athletes for competition. However, there is a lack of understanding about how coaches approach collision training prescription. While exercise prescription principles such as frequency, intensity, type, duration, and volume are well-established in muscle resistance literature, their application to collision training is limited. In both team and individual collision sports, athlete collisions are the leading cause of injuries, affecting player well-being and team performance significantly. Although injuries occur less frequently during training compared to matches, the risk of training-related injuries remains a concern. To enhance performance and reduce injuries in collision sports, further research is required in this field.

Aim and Objectives

This dissertation aimed to explore the perspectives of elite coaches regarding collision training prescription. The objectives were to: a) explore the current collision training perspectives of elite collision coaches for collision training planning, necessity, and risk; b) describe the established exercise prescription parameters such as frequency, intensity, duration, activity, and volume regarding collision training prescription; and c) describe differences in collision prescription across the participants.

Methodology

We conducted a qualitative descriptive study using semi-structured interviews via Zoom. We analysed the interview data systematically using thematic analysis and the NVivo 12 software. We recruited six elite male collision coaches, including three from rugby union, two from mixed-martial arts (MMA), and one from boxing, using purposeful sampling via social media. Coaches who did not provide informed consent were excluded.

Results

In theme one, we found that elite coaches had prior experience as elite athletes, influencing their views on collision training planning through personal experience and interactions with fellow coaches. Theme two revealed that coaches took a comprehensive approach to prescribing collision training. They considered athlete conditioning, skill development, and realistic match simulations. They also adjusted collision training intensity, volume, frequency, and duration based on the competition date. Differences were noted between sports, with MMA and boxing having more frequent and longer collision training sessions compared to rugby union. Protective equipment was consistently emphasised. In theme three, coaches adapted collision training when athletes were injured and consulted other specialists. They used both subjective measures, like verbal intensity scales, and objective tools, such as Global Positioning System (GPS) in rugby union, for monitoring and adjustments. This approach ensured safety and performance in collision sports.

Conclusion

This dissertation was the first multinational study researching the perspectives of elite coaches from diverse sporting backgrounds regarding collision training. Over time, collision training methods have evolved, especially in rugby union, where coaches now advocate for shorter yet more intense collision sessions, all while prioritising the use of protective gear. This shift towards shorter training durations underscores a growing emphasis on athlete well-being. While the direct practical application and generalisability of these findings to the broader coaching community may be limited, this dissertation serves as a valuable resource for gaining an evidence-based insight into how coaches approach collision training prescription. Future research should progress into stage three of the Translating Research into Injury Performance Practice (TRIPP) framework and should also consider the development of comprehensive injury prevention programmes specifically tailored for collision training prescription in various sports.

CHAPTER ONE: INTRODUCTION

1.1 Background

American football coach Vincent Lombardi contextualised collision sports as, "football is not a contact sport; it is a collision sport. Dancing is a contact sport" (Maraniss, 1999). The term 'collision sports' variably describes sports containing vast collisions among athletes and the playing surface (Naughton et al., 2020). Researchers have described these sports as full-contact, combat, and impact sports. However, for the present dissertation, the term 'collision sports' will be used to encompass all of these definitions. Collision sports include rugby league, rugby union, American football, boxing, and mixed martial arts (MMA; Loosemore et al., 2015; Naughton, Miller, & Slater, 2018; Thomas & Zamanpour, 2018). These sports contain extraordinary collisions between athletes, resulting in injuries (Naughton et al., 2018). Coaches prescribe collisions in training to prepare athletes for matches, but there is little practical research regarding optimal collision prescription (Hendricks et al., 2018). In the following two paragraphs, MMA and rugby union will be addressed as sports relevant to South Africa, one more recently popularised and the other well-established. Following, the importance of collision training, a preseason collision programme, and the collision training environment will be explained.

Mixed martial arts is a newly established collision sport. While MMA has its roots in 648 BC, the Ultimate Fighting Championships (UFC) re-introduced the sport in the 1990s and, to date, has grown exponentially around the globe, attracting millions of televised viewers and live crowds reaching tens of thousands (Andreasson & Johansson, 2019). Initially, MMA analysts referred to the sport as brutal and without rules and ethics; however, the UFC has enhanced its legitimacy by modifying the sport and adding rules to protect the athletes (Andreasson & Johansson, 2019). In addition to the UFC, forms of MMA include Pride and K-1 internationally (Delory, Sirost, & Roland, 2018), and the Extreme Fighting Championships (EFC) in Africa. The EFC hosts 10 MMA competitions annually in South Africa, with more than 300 athletes competing since 2009 (Venter, Janse Van Rensburg, Fletcher, & Grant, 2017).

As a well-established collision sport, rugby union has an estimated 8.5 million players across 121 countries, including South Africa, where >50% of injuries occur during tackling (Hendricks et al., 2018). The frequency and intensity of collisions in professional rugby union result in a substantial risk of injury for players (Williams, Trewartha, Kemp, & Stokes, 2013). While rugby union players have an enormous injury burden, the sport is marvelled at by hundreds of millions of fans (World Rugby, 2021). In most collision sports, the injury incidence is lower during training than in competition due to increased levels of control (Bayram, Hamilton, & Saunders, 2020; Kay et al., 2017; Krill et al., 2017; Thomas & Thomas, 2018; Williams et al., 2013). However, in certain circumstances researchers have highlighted greater injury incidence during training than in competition (Loosemore et al., 2015).

Training for sports involves applying stressors to the body to improve physical and tactical capacity and sporting performance (West et al., 2021). Coaches prescribe training loads intended to induce physiological change. Coaches must apply training loads periodically to align with the athlete's individual needs, tactical requirements, and the competitive demands of the sport (West et al., 2021). Therefore, the correct guidance from coaches during training allows for the appropriate conditioning of athletes for a match (Naughton et al., 2018; West et al., 2021). According to Hendricks, Karpul, and Lambert (2014), collision skills such as tackling, muscle power, and sprinting allow rugby union players to adapt to collisions technically and physiologically. Naughton et al. (2018) proposed that exposure to collisions during training could induce a repeated bout effect, demonstrating player adaptation to collision exposure and making them less susceptible to injury. In contrast to developing susceptibility to collision injury, collision training also includes collision skill development.

For athletes to improve their collision skills, coaches require a detailed preseason skill training framework and measurement plan (Hendricks et al., 2018). A well-constructed preseason collision program in rugby union may benefit athletic development aimed at preparing athletes for competition through skill development, improved performance, and injury prevention.

When implementing collisions during training, coaches should identify the skill level and age of the athlete, as younger, less-skilled athletes would require a more significant number of sessions before progressing to more intense skill loads. Researchers have recommended testing the technical skill level of the athlete through a set of criteria during a one-on-one tackling drill between a tackler and a ball carrier.

Following this, coaches should determine the training session's purpose, which may include learning the correct tackle, developing and refining technical proficiency, building technical capacity, and building skill capacity. After determining the purpose, coaches should apply the tackle skill framework to plan and design training sessions. Coaches can use internal measurements such as the rate of perceived exertion (RPE) to monitor and optimise training (Hendricks et al., 2018; Schwellnus et al., 2016).

For athletes to effectively transfer skills acquired in training to competition, the training environment should be representative of the competitive environment to allow athletes to improve their decision-making capacity (Davids, Araújo, Vilar, Renshaw, & Pinder, 2013). Athletes cannot thoroughly plan their specific sports actions, react to information in the environment, and perform actions without prior exposure (Araujo, Davids, & Hristovski, 2006). The decision-making behaviour of successful athletes must be eminently anticipatory and cyclical, based on the perception of crucial information sources from their actions and the external environment (Araujo et al., 2006).

According to Araujo et al. (2006), "Through the search for relevant information to achieve specific competition goals, athletes can induce the occurrence of certain interactions with the environment that facilitate goal achievement" (p. 672). The theory of ecological dynamics suggests that learning occurs through the performer-environment relationship and therefore highlights the importance of coaches simulating the competition environment during training for athletes (Hirschhorn et al., 2018).

Researchers have called for the development of a rugby union collision training program that details all forms of contact and collision training parameters including the frequency, intensity, and duration of collisions, as well as the conditions and the number of sessions (Hendricks, Till, Brown, & Jones, 2017). Further, there is a necessity for evidence-based training programs to describe the safe prescription parameters of collision training (Hendricks et al., 2018; Roe et al., 2017). In cases where these frameworks exist, they remain theoretical and untested for efficacy in practice (Hendricks et al., 2018). Thus, by exploring coaches' perspectives on collision training prescription using a descriptive qualitative study, we will be able to provide an evidence-informed description of collision training prescription that can be used by collision coaches, athletes, and medical staff such as physiotherapists working across participation levels, ranging from grassroots to professional.

1.2 Theoretical Framework and Dissertation Scope

Coaches can optimise training preparation and prevent injuries in collision sports by following a detailed collision training programme (Hendricks et al., 2018). The Translating Research into Injury Prevention Practice (TRIPP) framework proposes that only research that sports coaches, participants, and sporting bodies adopt will prevent injuries (Finch, 2006). This dissertation aims to contribute to injury prevention literature in collision sports by understanding the collision training prescription by elite coaches. The TRIPP framework (see Figure 1) involves six steps for sports injury prevention (Hendricks et al., 2018).

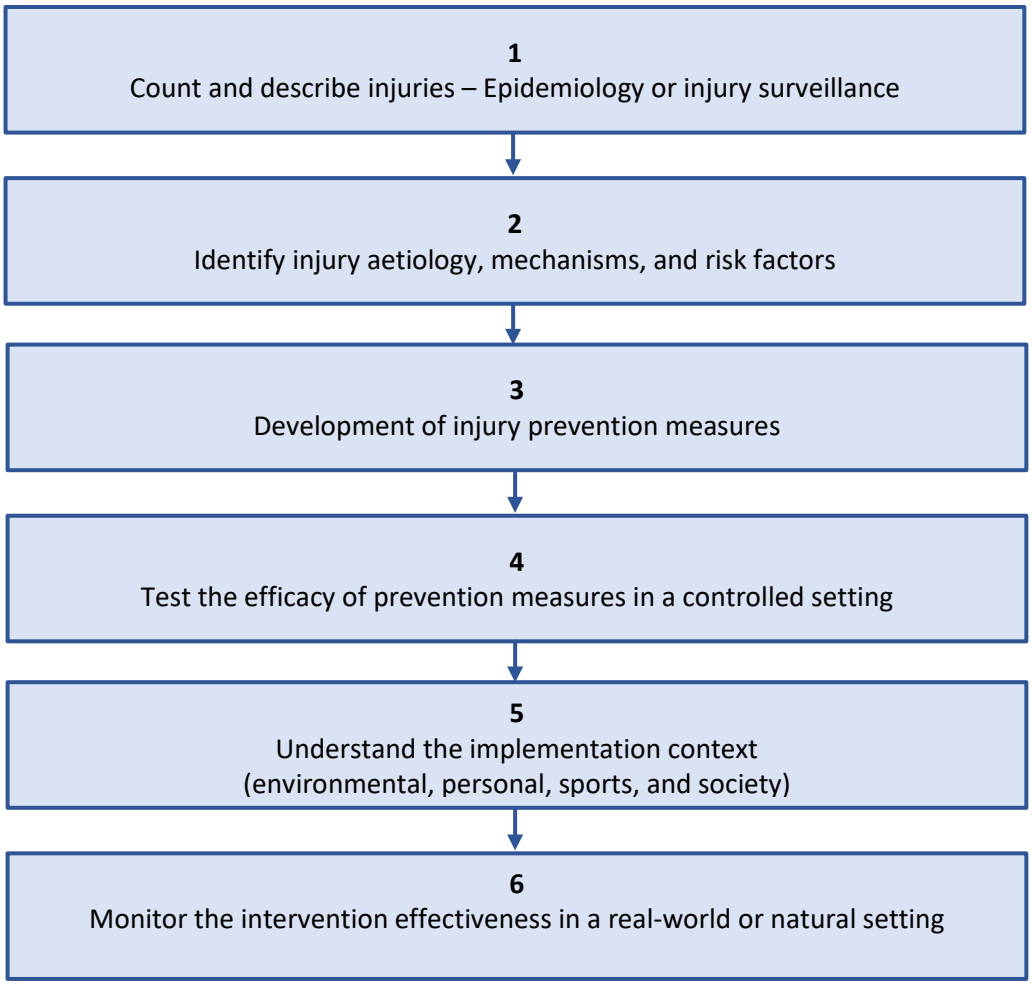

Figure 1. The Six Steps of the Translating Research into Injury Prevention Practice (TRIPP) model.
(re-drawn from Finch and Donaldson (2010) using our own graphics)

Collision training prescription is crucial for optimal match preparation, specifically for injury prevention, through reducing susceptibility to injury from training (Hendricks et al., 2018). Researchers suggest stage three of the TRIPP framework should include studies on models of the human system including (human tissue, i.e., muscles; Finch, 2006). Thus, we interviewed coaches who prescribe collisions to athletes on a professional basis.

The present dissertation has been positioned in step three of the TRIPP framework, focusing on understanding how elite coaches mitigate collision injury risk through their training prescription. Stage three is based on the premise of the high injury burden from sporting collisions tackles demonstrated in stage two of the TRIPP framework (Hendricks et al., 2018).

Researchers suggest that to go beyond stage two, it is crucial to develop a potential injury prevention measure (Hendricks et al., 2018). Therefore, we aimed to explore the current collision training perspectives of elite collision coaches for collision training planning, collision necessity, and risks.

1.3 Aims and Objectives

1.3.1 Aims

The aim of the present research was to explore the perspectives of elite coaches regarding collision training prescription.

1.3.2 Objectives

The objectives of the study were to:

a) explore the current collision training perspectives of elite collision coaches for collision training planning, necessity, and risks;

b) describe the established exercise prescription parameters such as frequency, intensity, duration, activity, and volume, regarding collision training prescription; and

c) describe differences in collision prescription across the participants.

1.4 Plan of Development

Chapter Two will provide a comprehensive review of the literature concerning the necessity of collision training, collision sports mechanics, the epidemiology of collision injuries, measuring and monitoring collision training, and prescribing collision training. Headgear and other protective collision equipment will also be reviewed. The methodology employed when conducting this research will then be outlined in Chapter Three. Chapter Four will provide a detailed presentation of the study results, which will be discussed in Chapter Five. A final summary and conclusion will be presented in Chapter Six.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The present literature review forms part of the minor dissertation on exploring the perspectives of elite coaches regarding collision training prescription. Exposure to collisions during training is a prerequisite to prepare athletes for the demands of competition (Gabbett, Jenkins, & Abernethy, 2010). While exposing athletes to collision training may improve conditioning, there is also a risk of fatigue, overtraining, and injury. In addition, athletes require collision skills for game success. Therefore, it is necessary for coaches to understand collision training guidelines, to prescribe collisions in training appropriately, ensuring athlete conditioning and avoiding injury. There are no other studies looking at coaches' perspectives in contact/collision sports regarding collision training prescription. We investigated exercise prescription parameters such as frequency, intensity, duration, activity, and volume, across different collision sports. Moreover, proficient tackling skills in a match reduces injuries and increases tackling success (Hendricks et al., 2018). The ability to tackle, tolerate the tackle, and win the tackling contest are strong predictors of winning a match in collision sports (Gabbett, Stein, Kemp, & Lorenzen, 2013).

2.1.1 Databases and Search Terms

EBSCOhost, PRIMO, and Google Scholar were searched from April 2021 to July 2022 to source information for this review. EBSCOhost databases included: Academic Search Premier, Africa-Wide Information, CINAHL, ERIC, MEDLINE, and Rehabilitation and Sports Medicine Source. Keywords included: *contact training "OR" collision training "AND" impact-induced muscle damage "AND" exercise-induced muscle damage "AND" collision biomechanics "OR" collision mechanics "AND" injury epidemiology "OR" injury incidence "OR" injury prevalence "AND" injury prevention "AND" load measurement "AND" load monitoring "AND" exercise prescription "AND" training program "OR" training framework "AND" coaching learning or knowledge.*

The abovementioned keywords pertained to the following collision sports keywords: *rugby union "OR" rugby league "OR" American football "OR" wrestling "OR" mixed martial arts "OR" boxing.*

2.1.2 Literature Review Scope and Structure

The following review is presented to identify literature on the current collision prescription guidelines and commonalities between different collision sports. The primary topics reviewed includes an introduction to coaching, collision injury epidemiology, measuring and monitoring collision training, and the prescription of collision training. These primary topics were reviewed to enhance the understanding of performance enhancement and injury prevention, specifically regarding prescribing collisions in the selected collision sports setting.

The literature review design was presented in the form of a narrative review. “A narrative review attempts to identify what has been written on a subject or topic” (Paré, Trudel, Jaana, & Kitsiou, 2015, p. 185). The search process was not exhaustive, and we exercised judgement to determine that the data presented below was representative of the current understanding of collision prescription in sports (Furley & Goldschmied, 2021). We included rugby union, MMA, and boxing participants within the dissertation. However, the literature review also encompassed other collision sports, including American Football and wrestling. Before coaches prescribe collision training to athletes, they plan their training sessions. The following section briefly introduces the practice of coaching planning.

2.2 Coaching as a Planning Process

For coaches, the ability to plan and rationalise through coaching practice is a factor of coaching effectiveness and experience (Abraham et al., 2014). Expert coaches plan and reflect on understanding the nature and development of problems before developing a plan of action to solve them (Abraham et al., 2014). Klein (2009) defines experts as those having the skills and abilities to perform at the highest level.

However, planning in coaching is a complex process requiring an understanding of multiple facets like performance cycles and prescription parameters such as frequency, intensity, and training volume (Abraham et al., 2014).

Coaches require understanding frameworks that aid planning, such as the interaction between understanding the learner, the curriculum, and the environment (Abraham et al., 2014). According to Klein (2009), informal judgment is inconsistent, as shown by human judges reaching different conclusions on the same case. The literature has demonstrated that expert coaches can plan to achieve performance development (Abraham et al., 2014). Further, coaches prefer to acquire knowledge from informal sources (see Table 1). Coaches with non-tertiary qualifications may require assistance interpreting specific sports-science-related information (Stoszkowski & Collins, 2016; Williams & Kendall, 2007). Sports-science information includes injury epidemiology (which is presented after the table below); however, we highlighted this information in lay language with more specific injury statistics in several collision sports.

Table 1. Coaching Literature.

AUTHOR	TITLE	SAMPLE SIZE/ POPULATION	AIM	FINDINGS	STUDY DESIGN
Williams and Kendall (2007)	Perceptions of elite coaches and sports scientists of the research needs for elite coaching practice.	Level three coaches (nationally accredited) from the Australian Sports Commission's Coaching and Officiating Unit (n=222). More than 90% had more than 10 years' experience, 51.7% had a bachelor's degree or higher, 84.6% were male coaches, and 15.4% were female coaches.	To determine (in an Australian context) how elite coaches and sports science researchers perceived the research needs of elite coaching practice.	Elite coaches perceived a requirement for more research in sports psychology, dissemination of research findings via coaching clinics and sports magazines, and using more appropriate lay language in information dissemination.	Survey + interview questions
Stoszkowski and Collins (2016)	Sources, topics, and use of knowledge by coaches.	Female (n=31 - primarily from USA) and (n=289 males – primarily from UK). Majority soccer coaches and most possessed a postgraduate qualification.	To explore coaches' perceptions of their actual and preferred methods of acquiring new coaching knowledge, the types of knowledge they currently acquire and/or desire, and their application of new knowledge.	Peer discussion: 186 participants' (41.52%) preferred methods of acquiring coaching knowledge; other coaches/colleagues 248 (55.36%); informal learning 415 (92.63%). How participants perceive they have used the knowledge acquired: Applied/used in practice immediately 175 (54.18%) vs. uncritical application 236 (73.07%).	Survey
Abraham et al. (2014)	Planning your Coaching: A focus on Youth Participant Development.	No sample size. Sports coach population.	To offer ideas as to why coaches should engage in planning.	The coaches' capacity to plan and rationalise through coaching practice is a determining factor of coaching expertise and effectiveness. Planning is crucial in the development of a coach since it encourages deep thinking, raises expectations of both coach and player, and provides a template from which thoughtful reflection can occur post-delivery. They argue that the macro and meso-level of goal setting should predominantly be where deliberate thinking and problem-solving should occur. Also, that completing this level of thought should set coaches up to engage in efficient and accurate intuitive decision-making in micro situations.	Book chapter

2.3 The Epidemiology of Collision Injuries in Collision Sports

Injury epidemiology relates to the present research as it provides information which may be crucial to coaches and other sports specialists in collision training injury prevention. Epidemiology studies are the building blocks for sports injury prevention programmes and ultimately aim to protect the health of athletes (Bahr et al., 2020). In the following section, injury within the sports context is defined, followed by an explanation of data on injury rates, anatomical injury location, and injury diagnosis in collision sports.

2.3.1 Defining Injury in Collision Sports

According to the International Olympic Committee, "injury is tissue damage or other derangement of normal physical function due to participation in sports, resulting from rapid or repetitive transfer of kinetic energy" (Bahr et al., 2020, p. 3). As outlined in Table 2 below, most researchers defined an injury in collision sports as an event occurring either during training or competition, resulting in specified time-loss from sports in rugby union, American football, boxing, and wrestling (Bayram et al., 2020; Kay et al., 2017; Williams et al., 2013). However, for more recently established sports such as MMA, the injury epidemiology has only been studied since 2006 (Bledsoe, Hsu, Grabowski, Brill, & Li, 2006) and, as a result, the injury definition is unclear (Lystad et al., 2014b). For the present review, injury was defined as time-loss from training or competition. Injury severity was defined by the specific amount of time that a participant was injured, and ranged from minor (2 to 8 days) to severe (21 to greater than 28 days; Dompier, Powell, Barron, & Moore, 2007; Kay et al., 2017; Williams et al., 2013).

Table 2. Injury and Severe Injury Definitions used in Collision Sports.

SPORT	DEFINITION
AMERICAN FOOTBALL	A physical complaint from a training session or match from the 2014-2015 BUCS American football season led to time loss from training or matches (Bayram et al., 2020). Time-loss severity included minor (8 days), moderate (8 to 21 days), and severe (21 days) (Dompier et al., 2007). A severe injury results in time loss of greater than 21 days of participation (Kay et al., 2017).
BOXING	Any musculoskeletal condition that prevented the boxer from participating in either training or competition for greater than 24 hours (Loosemore et al., 2015).
MMA	An injury that resulted in an athlete receiving medical attention (Lystad, Gregory, & Wilson, 2014a).
RUGBY UNION	"A physical complaint, caused by an energy transfer that exceeded the body's ability to maintain its structural and functional integrity, sustained by an athlete during a rugby match or training, irrespective of the need for medical attention or time-loss from rugby activities" (page 2) (Fuller et al., 2007). An injury was graded based on time lost from competition and training: minimal (2-3 days), mild (4-7 days), moderate (8-28 days), and severe (>28 days) (Williams et al., 2013).
WRESTLING	An injury was defined as damage to the body leading to an inability to train or compete normally (Noh et al., 2015). A severe injury results in time loss of greater than 21 days of participation (Kay et al., 2017).

2.3.2 Injury Rate of Collision-Related Injuries in Training and Competition in Collision Sports

Across collision sports, injuries occurred more frequently in competition than in training (Table 3). A meta-analysis by Williams et al. (2013) reported that the highest injury rate was observed during international matches, whereas the lowest was during club training. The ratio of injuries in collegiate American football and wrestling was eight times higher during competition than training (Kay et al., 2017), indicating a consistently higher competition injury rate when compared to training injury rates. In contrast, professional amateur boxers from the United Kingdom sustained more injuries during training (n=209; 70%) than during competition (n=88; 30%; Loosemore et al., 2015).

2.3.3 The Anatomical Injury site in Collision Sports

In rugby union, American football, and wrestling, the knee was the most frequently injured site (Kay et al., 2017; Thomas & Thomas, 2018; Williams et al., 2013). In contrast, for MMA and boxing, the head/face was the most frequently injured area (Bromley, Drew, Talpey, McIntosh, & Finch, 2018; Thomas & Zamanpour, 2018). While Table 3 includes numerical information for rugby union presented as injuries per 1000 player hours (PH), the remainder of the studies used a percentage value to demonstrate the proportion of sites injured for the other collision sports.

2.3.4 The Injury Diagnosis or Injury Type in Collision Sports

The percentage presentation of injury diagnosis is similar in rugby union, American football, and wrestling. A muscle or muscle sprain was the most frequent injury diagnosis, followed by a tendon or ligament strain (Kay et al., 2017; Williams et al., 2013). In boxing, the highest injury diagnosis was ligamentous injury, specifically to the hand (Loosemore et al., 2015). Nevertheless, for boxing and MMA the percentage presentation of injury diagnosis was similar, with contusions, lacerations, and abrasions being the most frequent injury type, followed by bony fractures (Lystad et al., 2014a; Thomas & Zamanpour, 2018; Zazryn, McCrory, & Cameron, 2009).

Table 3. The Rate, Location and Diagnosis of Collision-Related Injuries in Training and Competition.

SPORT	AIM	POPULATION	PROTOCOL	FINDINGS		
				Injuries per 1000 Athlete Exposure		
AMERICAN FOOTBALL & WRESTLING (Kay et al., 2017)	To describe the epidemiology of severe injuries in 25 National Collegiate Athletic Association (NCAA) sports in the 2009-2010 through 2014-2015 in USA		Descriptive epidemiology study	A. Men's American Football <u>Severe injury rates in competition vs training</u> (4.79/1000 AE) competition (0.56/1000 AE) training (1.73/1000 AE) severe injury <u>Severe injury rates over the season</u> (0.95) preseason (1.01) regular season (0.55) post season <u>Injury site</u> Lower limb: knee (40.6 %), ankle (20.0 %), hip/groin/upper leg (6.2%) Upper limb: shoulder (9.5%), elbow (3.8%), wrist/hand (3.8 %) Head/neck/face: (9.41%) Trunk: (5.3 %)	B. Men's Wrestling <u>Severe injury rates in competition vs training</u> (8.26/1000 AE) competition (0.95/1000 AE) training (1.73/ 1000 AE) severe injury <u>Severe injury rates over the season</u> (1.30) preseason (1.94) regular season (1.55) post season <u>Injury site</u> Lower limb: knee (32.4 %), lower leg/ ankle/foot (3.5%), hip/groin/upper leg (2.3%) Upper limb: shoulder (16.8%), wrist/hand (6.4%) elbow (5.8%), Head/neck/face (24.9%) Trunk (5.8%)	<u>Severe injury rates in competition vs training</u> (8.26/1000 AE) competition (0.95/1000 AE) training <u>Injury Diagnosis Type</u> Muscle (39.4 %) Tendon, ligament, ligament strain (17.3 %) Concussion (6.8%) Bony fractures (14.4%) Contusions, laceration, and abrasions (2.0%)

Table 3 continued.

SPORT	AIM	POPULATION	PROTOCOL	FINDINGS	
				Injuries per 1000 athlete exposure	
AMERICAN FOOTBALL (Krill et al., 2017)	To compare injury rates based on competition versus practice, time in season, mechanism of injury, and exposure types (live contact, full-pads, and non-contact)	American Football	Retrospective study	<u>Training vs competition</u> (3.25 /1000 AE) training (11.56/1000 AE) competition <u>Time of the season</u> (5.76/1000 AE) preseason (4.26/1000 AE) first half (3.05/1000 AE) second half <u>Contact injuries over a season</u> (3.29/1000 AE) preseason (2.45/1000 AE) first half (1.91/1000 AE) second half	<u>Exposure types</u> (5.70/ 1000 AE) live contact (2.66/ 1000 AE) full-pad exposure (0.78/1000 AE) non-contact <u>Injury site</u> Not reported <u>Injury Diagnosis or Injury Type</u> Not reported
AMERICAN FOOTBALL (Bayram et al., 2020)	To describe the epidemiology of American football injuries, in the United Kingdom	American Football male university players (n=410) from the UK. Average age 21.3 years; range 18-37 years	Descriptive epidemiology survey-study	<u>Injury rate</u> 173.2/100 athlete-seasons <u>Injury site</u> Lower limb: knee (10.2%), ankle (8.4), upper leg (3.6) Upper limb: shoulder (17%), hand (6.9%) Head: (6.6%) Trunk: (3.0%)	<u>Injury Diagnosis or Type</u> Tendon, ligament, ligament strain (28%) Muscle (19%) Bony fractures (15%) Concussion (6.6%) Contusions, laceration, and abrasions (1.7%)
BOXING (Loosemore et al., 2015)	To review injuries in training and competition in the Great Britain amateur boxing squad between 2005 and 2009	Amature male boxers (n=55)	5-year longitudinal prospective injury surveillance study	<u>Injury rate</u> competition (828/1000 hours) <u>Injury site (% not reported)</u> The hand	<u>Injury Diagnosis or Type (% not reported)</u> Sprain and ligament injuries

Table 3 continued.

SPORT	AIM	POPULATION	PROTOCOL	FINDINGS		
				Injuries per 1000 player hours (PH)		
RUGBY UNION (Williams et al., 2013)	To review and gather epidemiological injury data in men's professional Rugby Union	Professional male Rugby union players	Meta-analysis	<u>Competition vs. training</u> (81/1000 hours) competition (3/1000 hours) training <u>Level of play</u> (123/1000) international match (89/1000) level one club match (35/ 1000) level two club match (3/1000) international and level one club training <u>Mean injury severity</u> Level two club (23 days) Level one club (21 days) International (20 days) <u>Playing position:</u> frontline players (94/1000) backline players (99/1000)	<u>Severity of injuries</u> moderate (28/1000 PH) mild (23/1000 PH) minimal (17/1000 PH) <u>Period of the match</u> 40-60 minutes (119/1000 PH) 20- 40 minutes (112/1000 PH) 60- 80 minutes (108/1000 PH) 20 minutes (57/1000 PH) <u>Injury site</u> lower limb (47/1000 PH; 19 days) upper limb (14/1000 PH; 32 days) head/neck/face (12/1000 PH; 12 days) trunk (9/1000 PH; 16 days)	<u>Injury Diagnosis or Type</u> Muscle (40/1000 hours; 15 days) Tendon, ligament, ligament strain (34/1000 hours; 29 days) Concussion (7.9 to 21.5 injuries/1000 PH) Bony fractures (4/1000 hours; 42 days) Contusions, laceration, and abrasions (1/1000 hours; 6 days) <u>New vs. recurrent injuries</u> new (78/1000 hours) recurrent (11/1000 hours)

Table 3 continued.

SPORT	AIM	POPULATION	PROTOCOL	FINDINGS	
MMA (Thomas & Zamanpour, 2018)	To assess injury rates in all MMA studies	Males (n=2407) & Females (n=108)	Systematic review	<u>Injury rate</u> (264.4/1000 AE) males (101.9/1000 AE) females <u>Injury site</u> Lower limb (7.5%) Upper limb (19%) Head (37%) Trunk (2.5%)	<u>Injury Diagnosis or Type</u> Contusions, laceration, and abrasions (62%) Bony fractures (9.9%) Tendon, ligament, ligament strain (not reported) Muscle (not reported) Concussion (not reported)
MMA (Lystad et al., 2014a)	To review MMA injury epidemiology data and estimate injury incidence and risk factor sizes	Sanctioned MMA competitors in the USA between 18-25 years of age	Systematic review and meta-analysis	<u>Injury rate</u> (228.7/1000 AE) average estimate <u>Injury site</u> Head (66.8% to 78.0%) Wrist/hand (6.0% to 12.0%)	<u>Injury Diagnosis or Type</u> Tendon, ligament, ligament strain (not reported) Muscle (not reported) Bony fractures (7.4%- 43.3%) Concussion (3.8%- 20.4%) Contusions, laceration, and abrasions (36.7%- 59.4%)
WRESTLING (Thomas & Thomas, 2018)	To identify all studies of injuries in wrestling, assess risk of bias, and compute weighted average injury rates	Male wrestlers (n=7338)	Systematic review	<u>Injury rate</u> 7.6/1000 min for boys (n=291) 17.5/1000 min for high school (n=520) 1.3/1000 min for collegiate (n=143), 7.7/1000 min for USA Big Ten universities (n=95). <u>Injury rate</u> (16.3/ 1000 AE) for 7/11 competition studies, (69.5/ 1000 AE) for 5/16 databases	<u>Injury site and percentage</u> Knee (24.8%) Shoulder (17.8%) Head (16.6%) <u>Injury Diagnosis or Injury Type</u> Tendon, ligament, ligament strain (28%) Muscle (19%) Bony fractures (15%) Concussion (6.6%) Contusions, laceration, and abrasions (1.7%)

***Key**: AE- athletic exposures, PH- player hours*

While injuries in rugby union are well documented (Williams et al., 2013), more recent studies have demonstrated an interest in understanding the effects of collisions on the skeletal muscle and how this may impact athletic performance (Naughton et al., 2018). The following section introduces exercise-induced muscle damage (EIMD) and impact-induced muscle damage (IIMD) and demonstrates the effects of collisions on skeletal muscle.

2.3.5 Differentiating between Exercise-Induced and Impact-Induced Muscle Damage

While EIMD and IIMD are not classified as injuries, their similarities and differences are explored as this is a common effect in all collision sports, and understanding these effects may enhance collision performance enhancement. Exercise-induced muscle damage results from a novel or unaccustomed exercise, specifically eccentric muscle loading (Naughton et al., 2018) and metabolic stress (Tee, Bosch, & Lambert, 2007). In contrast, IIMD is caused by compression of the skeletal muscle at the impact site and may occur from player-against-player collision or collision against the playing surface (Naughton et al., 2018). Following IIMD, injuries vary in severity from contusions and hematomas to more severe proliferation of bone within the muscle (Järvinen, Järvinen, Kääriäinen, Kalimo, & Järvinen, 2005; Smith, Kruger, Smith, & Myburgh, 2008). Therefore, it may be essential for researchers to highlight the specific effect of IIMD (such as contusion or hematomas) as these may present with specific symptoms that effect performance.

A recent systematic review highlighted that athletes experienced the highest levels of EIMD in the initial phase of preseason and included both non-collision (soccer, hockey, and rowing) and collision sports (rugby league, rugby union, American football, and wrestling; Simmons, Doma, Sinclair, Connor, & Leicht, 2021). However, Simmons et al. (2021) noted that the results of their study may have been impacted by the demands of the collision sports and may have influenced measurements of blood markers such as creatinine kinase in sub-elite and elite athletes.

This further emphasises the need to differentiate between studies investigating EIMD and IIMD, as in rugby union studies similar blood markers were both present and higher in player positions that underwent greater IIMD (Takarada, 2003).

In contrast, research on IIMD is scarce. Studies investigating IIMD were limited to animals involving drop mass-models (Smith et al., 2008). However, a study by Naughton et al. (2018) included 18 healthy males in an IIMD investigation. A 60kg smith machine bar was modified and dropped 26 times over 80 minutes on specific landmarks of muscle bellies including the anterior, lateral, and posterior thigh in a segmental pattern beginning distally, then proximally. The results demonstrated reduced speed (over 5m and 15m) and squat jump peak power for 48 hours following the IIMD protocol. There was no change in muscle damage (myoglobin) or inflammation (c-reactive protein) blood markers (Naughton et al., 2018).

Following muscle damage, both EIMD and IIMD undergo similar physiological process of inflammation and result in similar symptoms including delayed onset muscle soreness (DOMs) and performance decrements. Symptoms in both EIMD and IIMD included reduced muscle strength and joint range of motion (ROM) as well as muscle soreness (Naughton et al., 2018; Smith et al., 2008). However, in EIMD muscle soreness peaked between 24-48 hours after injury (Naughton et al., 2018), while muscle soreness in IIMD was elevated immediately after muscle damage (Naughton et al., 2018). Due to the strong similarities between EIMD and IIMD it is crucial for future studies to specify the research aims and protocols concerning both EIMD and IIMD. The most substantial difference between EIMD and IIMD was the mechanism of injury, where in EIMD occurred without collisions and IIMD with collisions (Naughton et al., 2018; Simmons et al., 2021; Takarada, 2003). Nevertheless, exposing athletes to collisions in training will result in IIMD (Naughton et al., 2018). Athletes will require a recovery period as IIMD decreases their optimal performance (Naughton et al., 2018).

Therefore, coaches must prescribe training carefully to ensure that athletes can recover from collision training within reasonable timeframes. Also, in considering IIMD in the collision sports setting, coaches should measure and monitor IIMD to enhance the athlete's performance. The following section covers the monitoring and measuring of collisions during training and competition.

2.4 The Necessity of Monitoring Collisions in Collision Training

Collisions during competition are the most significant source of injury in team sports such as rugby union; monitoring collisions is essential to prepare athletes for the match and avoid overtraining or injuries during training (Gabbett, 2016). Researchers have referred to monitoring as the periodic or continuous surveillance or testing of the preparedness and performance of elite athletes (Sands & Stone, 2006). Monitoring training can be essential to inform decision-making regarding the athlete, training management, and adjustments to training (Shushan et al., 2022). Coaches should monitor athletes to ensure that training causes the desired effects regarding performance and well-being (Saw, Main, & Gastin, 2016). Coaches must differentiate between internal and external load when understanding athletes capabilities and their appropriate training progression stimulus (Soligard et al., 2016). This section links the dissertation's objectives, as monitoring training collisions is essential for optimal training prescription, including collisions, and to avoid injury (Hendricks et al., 2019). In this section, the different types of loads or stresses experienced by athletes in collision sports are identified. The role of biomechanics in collision sports is then discussed, and the different types of subjective and objective monitoring tools researchers used to measure and monitor collisions in different sports will be highlighted.

2.4.1 Load Measuring and Monitoring in Collision Sports

Load or 'external load' occurs when an athlete or coach applies an external stimulus to the athlete resulting in physiological and psychological responses. Researchers refer the responses thereof as the athlete's 'internal load' (Schwellnus et al., 2016; Soligard et al., 2016).

Measuring external load includes quantifying training hours, the distance covered during training, the weight lifted, the number of games played, life events, daily hassles, or travel. In contrast, internal load measurements include the heart rate (physiological/objective) and rate of perceived exertion (RPE; physiological/psychological; Schwellnus et al., 2016). Moreover, to thoroughly understand the measurement and monitoring of collision training, the biomechanics of collisions should be explored. The external load from collisions can be quantified by kinetic and kinematic variables, which are subcomponents of biomechanics.

2.4.2 Biomechanics of Collisions in Collision Sports

Biomechanics involves the application of classical mechanics to living things (Nordin & Frankel, 2001). Researchers have classified biomechanics applications to human movement concerning performance enhancement and the reduction or treatment of injury (Knudson & Knudson, 2007). Most professionals who study movement prescribe technique changes, exercises, and give instructions to improve performance (Knudson & Knudson, 2007). Understanding biomechanics is the most beneficial for enhancing sports performance or activities where technique is a dominant factor (Knudson & Knudson, 2007). Coaches prescribing collisions require an understanding of how muscle functioning is affected when an external load or force is applied. Forces acting on athletes can create motion and stimulate growth and development but can overload tissues, causing injury (Knudson & Knudson, 2007).

The velocity of muscle functioning, specifically eccentric muscle contractions, is inversely related to the external load applied (Guyton & Hall, 1986). When the external load applied to the muscle decreases, movement is more efficient; but as load increases, the movement becomes less efficient (Nordin & Frankel, 2001). Understanding muscle functioning relates to collision training as sporting collisions encompass external loads between athletes and the environment (Naughton et al., 2018).

Therefore, coaches must prescribe the appropriate collision load to prepare athletes for the significant collision demands of the game and to avoid training injury. The following section aims to improve the understanding of collision biomechanics in collision sports by reviewing the literature on mechanics, separated into collision kinetics and collision kinematics in the various collision sports environments.

2.4.3 Collision Kinetics and Kinematics in Collision Sports

From a mechanical perspective, force-related factors have the greatest likelihood and severity of injury (Whiting & Zernicke, 2008). Force analysis falls within the sphere of mechanics known as kinetics and includes variables such as impact (Whiting & Zernicke, 2008). In collision sports, high-impact forces are commonly caused by collisions between athletes (Table 4). Nevertheless, kinematics is assessment of movement, by description, and includes variables such as acceleration, position, and velocity (Whiting & Zernicke, 2008).

From Table 4 below, in rugby league and rugby union, tackling force (kinetic variable) was linked to kinematic variables including tackle repetition, motion, contact time, and acceleration (Seminati, Cazzola, Preatoni, & Trewartha, 2017; Smith & Baer, 2020; Usman, McIntosh, & Fréchède, 2011). Repetitive tackling caused fatigue and decreased high-impact forces (Usman et al., 2011). Greater forces resulted from collisions, such as the dominant tackling shoulder in motion compared to the stationary tackle (Seminati et al., 2017). A shorter force impulse and decreased contact time were both associated with the dominant tackling shoulder in motion, and resulted in the most significant impact (Seminati et al., 2017). Also, tackling above the chest height resulted in greater head acceleration of two pairs of elite rugby league players (Tierney, Richter, Denvir, & Simms, 2018).

Also from Table 4 below, in combat sports such as boxing, punching force was linked to kinematic variables including punching technique, speed, and acceleration (Seminati et al., 2017; Smith & Baer, 2020; Usman et al., 2011).

Higher collision forces were related to specific punching techniques produced by more profound punching speeds (Beránek, Votápek, & Stastny, 2020; Zatsiorsky, 2008). Higher impact forces were related to skill level, as demonstrated by elite boxers emitting a more profound punching force than intermediate and novice boxers (Smith & Baer, 2020). Straight punches and reverse punches reached high speeds of over $10m.s^{-1}$ and provided a more significant impact than other upper limb strikes (Beránek et al., 2020). Older studies have demonstrated that the jab has a speed of $6m.s^{-1}$, while the hook has a speed of $8m.s^{-1}$ (Whiting, Gregor, & Finerman, 1988). A force of 784N for eight milliseconds produces head acceleration sufficient to cause a concussion (Zatsiorsky, 2008). While excellent collision technique like tackling may result in match success, it is also responsible for the most injuries (Gabbett et al., 2010). Collision injuries may also be due to inappropriate loads being placed on athletes during training or a match. Therefore, the different tools to monitor collision training will be discussed.

Table 4. Kinetic (impact) and Kinematics (impulse, speed, and acceleration) Variables in Collision Sports.

SPORT (AUTHOR)	AIM	POPULATION	PROTOCOL	FINDINGS
RUGBY UNION/ Kinetic (Usman et al., 2011)	To measure the shoulder force in the tackle, as well as the effects of shoulder padding on impact force	Laboratory participants (n=35) & field setting participants (n=98). All were males over 18 years of age with rugby experience from Sydney, Australia	Experiments were conducted in laboratory and field settings using a repeated measures design. The tackle force was measured with a custom-built force plate incorporated into a 45 kg tackle bag	Tackle repetition causes fatigue ($p = 0.010$) The first tackle (1743 N) The fifth tackle (1571 N) Field vs laboratory setting ($p = 0.047$) Field 1997 N Laboratory 1717 N No significant findings demonstrating force reduction through shoulder padding
RUGBY UNION/ Kinetic (Seminati et al., 2017)	To analyse the biomechanics of rugby tackling	Community and university level male rugby union players (n=15; aged 23.50 ± 5.10 years) from the United Kingdom	Demonstrating tackle impact forces by employing a repeated measure design	Front on-shoulder tackle force Dominant stationary shoulder (2930 N ± 740 N) Non-dominant stationary shoulder (2570 N ± 570 N). Moving dominant shoulder (3620 N ± 790 N) stationary dominant shoulder (2930 N ± 740 N)
BOXING/ Kinetic (Smith & Baer, 2020; Smith, Dyson, Hale, & Janaway, 2000)	To Identify differences in punch forces between elite, intermediate, and novice boxers from the United Kingdom with a self-developed boxing dynamometer	Elite, intermediate, and novice boxers (n=7) from the United Kingdom	Measuring punching force using a boxing dynamometer	Punching forces Elite boxers (4800N ± 227N) Intermediate (3722N ± 133N) Novice (2381N ± 116N)

Table 4 continued.

SPORT (AUTHOR)	AIM	POPULATION	PROTOCOL	FINDINGS
BOXING/ Kinetic (Halperin, Hughes, & Chapman, 2016)	To profile a professional boxer	Australian male boxer (n=1; age 23)	Case study	Punching force was the greatest 8 days after the match
RUGBY UNION/ Kinetic (Impact & Impulse) (Seminati et al., 2017)	To analyse the biomechanics of rugby tackling from: 1. A stationary position, 2. With dominant and non-dominant shoulder, and 3. And moving forward with the dominant shoulder	Community and university level male rugby union players (n=15; aged 23.50 ± 5.10 years) from the United Kingdom	Employing a repeated measure design, demonstrating tackle impact forces	<u>Impulse of Force</u> Stationary dominant shoulder (0.10s ± 0.01s) Stationary non-dominant shoulder (0.11s± 0.02s) Moving dominant shoulder (0.09s ± 0.02s) Stationary dominant shoulder (0.10s ± 0.01s) <u>Contact Time</u> Dominant stationary shoulder (0.10s + 0.01s) Non-dominant stationary shoulder (0.11s ± 0.02s) Dominant shoulder in motion (0.09s ± 0.02s) Dominant stationary (0.10s + 0.01s)
COMBAT SPORTS/ Punching Speed (Beránek et al., 2020)	To summarise and compare the mechanical consequences of different upper limb strikes across different sports	Elite athletes, self-defence, and military personnel. All these populations used upper limb strikes	Systematic review and meta-analysis	<u>Punching Technique and Speed</u> Straight punches and reverse punches in strength combat training and conditioning. These punches reach high speeds of over 10m.s^{-1} and provide a more significant impact than other upper limb strikes
RUGBY LEAGUE/ Impact and acceleration (Tierney et al., 2018)	To analyse 45 multibody, front-on-shoulder tackles using a video analysis approach and the MADYMO 50th percentile pedestrian model	Two pairs of elite rugby league players	Employing a repeated measure design, demonstrating tackle impact forces	The tackles experienced by the ball carrier had higher head kinematic values for linear and angular acceleration and a change in angular velocity for upper trunk tackles compared to mid or lower trunk tackles

2.4.4 Subjective Tools for Monitoring Collision Training

An athlete's performance is the ultimate indicator of their physical and psychological well-being and readiness to compete, but it is impractical to physically test athletes daily. In a systematic review, researchers have recommended improved quality subjective assessments to monitor athletes. Athletes well-being constantly responded to stress imposed by training and deteriorated with increased and chronic training loads (Saw et al., 2016). Also, subscales of subjective measures can evaluate non-training stress, fatigue, physical recovery, and general health/well-being which are all responsive to acute and chronic training (Saw et al., 2016).

In rugby union, researchers have previously tracked tackling proficiency by monitoring external workloads such as the duration, frequency, and number of repetitions during the session. Researchers now recommend including the rate of perceived challenge (RPC) to monitor athletes' internal load of tackle skill performance (Hendricks et al., 2019). Researchers have suggested that clinicians use the RPC to provide controlled movements and conditions (low RPC) to sport-specific conditions (high RPC). The coach can determine the RPC by determining the *challenge point.* The challenge point is the interaction between the *task difficulty* and the *available* information coaches provide to the athlete (Hendricks et al., 2019).

Researchers adapted the RPC framework from the RPE framework, an internal load monitoring tool typically using a visual analogue scale from 0-10 or 0-100 (Hendricks et al., 2019). The RPE monitors intensity with 0 depicting rest and 10 maximum exertion, intensity, or effort. In collision sports such as rugby union, researchers have used monitoring tools to prescribe collisions and have termed the tool as a contact or collision intensity scale (and will be further explained in the section on prescribing collision training). After integrating the RPE with skill acquisition theory, the RPC contains skill-specific instructions to quantify skill load (Hendricks et al., 2019).

The use of the RPC in rugby union highlights the precise nature of subjective monitoring measures used to quantify tackle skill execution. Nevertheless, in rugby union, collisions are most frequently measured by time-motion analysis and global positioning systems (GPS; Paul et al., 2022).

2.4.5 Time Motion Analysis in Rugby League, Rugby Union, and MMA

Time motion analysis (TMA) provides in-depth data; however, it is also time-consuming and interpretations may be subject to bias (Naughton et al., 2020). A recent systematic review highlighted that, in rugby union competitive matches ranging from collegiate to international level, TMA primarily quantified collision frequency. Thirty-seven studies quantified collision frequency in rugby union and provided averages alluding to 156.1 tackles, 116.2 rucks, and 22.0 scrums per match (Paul et al., 2022). Also, the average collision frequency during matches varied based on the players position, with rugby union forwards completing more tackles than backs (12.8 vs. 7.6).

Similarly, a systematic review by Naughton et al. (2020) highlighted that based on TMA, for collision frequency in rugby league forwards completed nearly twice the amount of tackles than backs per match (24.9 vs. 12.7). While researchers have repeatedly documented collision frequency using TMA in rugby league and rugby union, they have not thoroughly documented collision intensity. In classifying collision intensity using TMA, researchers in rugby league have calculated the velocity and acceleration, and in addition used a collision intensity scale (Naughton et al., 2020). Only one study quantified collision frequency during training in rugby union. It highlighted that 28.2 ± 3.3 tackles were conducted by novice players during small-sided games, while experienced players performed more tackles, 48.7± 3.3 tackles on average (Paul et al., 2022). While researchers have mainly used TMA to measure and monitor competition data in the team setting, they have also documented it in an individual sports setting.

Researchers have studied TMA to improve the time structure in MMA training programmes (Del Vecchio, Hirata, & Franchini, 2011; Lonergan, Tallent, & Lazarczuk, 2018). Expert evaluators conduct TMA by watching video recordings of the MMA bouts, indicating how the pace and actions, including collision activities such as striking, grappling, and groundwork, occur (Del Vecchio et al., 2011). Time motion analysis can inform MMA strength and conditioning programmes, changes between or integration of skill training, and technical-tactical preparation (Del Vecchio et al., 2011). According to Lonergan et al. (2018), when using TMA there is an average ratio of 1:4 between high and low-intensity efforts, as observed in 351 professional MMA bouts. The high-intensity actions were identified as between 6-14 seconds, whereas the low intensity actions were between 15-36 seconds (Miarka, Vecchio, Camey, & Amtmann, 2016). This highlights the necessity for a developed anaerobic system for repeated high-intensity efforts and a well-developed aerobic system for recovery periods (Lonergan et al., 2018).

The quantification of time in MMA matches may inform the preparation and development of the physiological requirements for successful combat (Lonergan et al., 2018). The time spent and actions conducted by MMA athletes vary, as collision events include quick strikes, extended wrestling, or grappling (Del Vecchio et al., 2011). In MMA, an example of collision training may consist of grappling/Jiu-Jitsu, wrestling, MMA sparring, and striking, all combined over a one-week period (Lonergan et al., 2018). Del Vecchio et al. (2011) suggested that training programs for regional-level MMA athletes focus on high-intensity ground striking or groundwork submissions, as more than half of all 52 matches ended in high-intensity groundwork conditions. Time Motion Analysis is crucial in informing exercise prescription principles including collision frequency in rugby union (Paul et al., 2022) and both collision frequency and intensity in MMA (Del Vecchio et al., 2011; Lonergan et al., 2018). In addition to TMA, researchers have used microtechnology devices such as GPS in team and individual sports (Naughton et al., 2020).

2.4.6 Quantifying collisions in Rugby League, Rugby Union, and MMA using the Global Positioning System

Microtechnology devices are GPS combined with embedded inertial sensors (Naughton et al., 2020). In a review of the validity and reliability of GPS in team sports, researchers have highlighted that 10Hz GPS devices were the most valid and reliable for linear and team sports running (Scott, Scott, & Kelly, 2016). In rugby union, researchers have used microtechnology devices to quantify collision frequency and intensity (Paul et al., 2022). Sixteen studies on rugby union highlighted the collision frequency, with forwards experiencing an average of 52.5 *very heavy impacts* and 10.8 *severe impacts,* and backs experiencing an average of 41.7 *very heavy impacts* and 6.7 *severe impacts* (Paul et al., 2022).

In rugby league, forwards experienced up to 44.0 collisions per match, while backs experienced 26.0. Nonetheless, these studies were highly heterogenous (Naughton et al., 2020). A study using the Minimax X (GPS) highlighted that the GPS (Minimax team S4 Catapult Innovations, Australia; 10Hz) and triaxial accelerometer (100Hz) offered real-time measures of collisions in 182 rugby league players (age 24.3 ± 3.3 years), and repeated high-intensity efforts primarily in forwards and hookers (Gabbett, 2015). Gabbett (2015) attempted to quantify athletes' wrestling and grappling movements while standing and on the ground and highlighted that these grappling and wrestling-like collisions occurred at speeds less than two meters per second. Nevertheless, the GPS could not differentiate between attack or defence collisions. Global Positioning Systems have been used in team collision sports and researched in individual collision sports (Kirk, 2014; Shushan et al., 2022).

Researchers have used GPS to measure external loads such as fatigue, readiness, and non-functional overreaching in MMA training (Kirk, Atkins, & Hurst, 2020). In an MMA study, researchers used an

accelerometer (Minimax X3 100-Hz triaxial accelerometer, Catapult Innovations, Australia) to measure the total player accelerations during simulated sparring matches (Kirk et al., 2020).

The authors concluded that the accumulation of player load, defined by the number of minutes in which athletes performed active movements, changed minute-to-minute, allowing fatigue to be highlighted (Kirk et al., 2020). Regardless, the accelerometers could not distinguish between high and low-intensity standing and ground movements (Kirk et al., 2020). Also, these results could not be transferred to competition sparring due to the small sample size (n=6 males; Kirk et al., 2020). While the use of GPS is well-documented, researchers use additional microtechnology devices to measure and monitor collisions in team sports (Duma et al., 2005; Shushan et al., 2022).

In collegiate American football, Duma et al. (2005) measured and analysed the head accelerations of 38 players from the Virginia Tech University American Football team in over 38 training sessions and 10 games. The wireless Head Impact Telemetry (HIT) system (Simbex, Lebanon, NH) provided real-time data to a signal receiver and laptop. Duma et al. (2005) concluded that the real-time impact system effectively collected thousands of head impacts and provided data that could be used with clinical evaluation to advance return to play (Duma et al., 2005).

Therefore, it is clear that using GPS (Minimax X3 triaxial accelerometer) in rugby league, rugby union, and MMA is useful for collision training preparation as it has the potential to quantify external load such as fatigue, distance covered, and collision frequency (Gabbett, 2015; Kirk et al., 2020; Naughton et al., 2020; Paul et al., 2022). The GPS provides a non-biased measure compared to TMA (Kirk et al., 2020); however, there is a low level of evidence to support the validity of GPS to quantify collisions in rugby league, rugby union, and MMA. Kirk et al. (2020) recommended that future studies considered a larger cohort of participants in MMA. While collegiate American football researchers have quantified thousands of head impacts using microtechnology devices (Duma et al., 2005), rugby union researchers do not have access to this method of analysis as wearing a helmet is not mandatory in these sports (Barnes, Rumbold, & Olusoga, 2017).

This section has highlighted that measuring and monitoring collisions using TMA, microtechnology devices, and subjective measures have added benefits for collision training prescription. While microtechnology devices measure external load, subjective measures are beneficial for measuring internal load. Researchers advocate for the use of both TMA and GPS to monitor external load (Naughton et al., 2020; Paul et al., 2022), and subjective measures such as the RPE and RPC to monitor internal load (Paul et al., 2022; Saw et al., 2016).

2.5 Prescribing Collision Training

Understanding what constitutes 'load' in collision training prescription may be complex, requiring the coach to understand the athletes' physical characteristics and the magnitude at which coaches prescribe collisions. Therefore, coaches should consider the athlete as the 'load' specifically when conducting collision drills such as tackling, striking, or grappling. The athlete can apply external load by varying magnitudes such as frequency, intensity, and duration (Schwellnus et al., 2016). Similarly, Kraemer and Ratamess (2004) reported that loading is dependent on variables of magnitude including exercise frequency, intensity, and type. In their study, loading was defined as the amount of weight lifted or the exercise resistance (Kraemer & Ratamess, 2004). While researchers have documented exercise prescription in resistance training concerning applying external load, research on collision training prescription is limited to the technical aspects of the load (collision) and not to specific exercise prescription principles such as intensity, frequency, and periodisation. In this section, we highlight the inclusion of collision prescriptions for injury prevention (warm-ups) and performance optimisation (collision training prescription).

2.5.1 National Injury Prevention Warm-Up Guidelines in Rugby Union

Warm-up preparation for match conditions during training is a requirement for both athletes and coaches to understand.

Evidence-based injury prevention programmes such as BokSmart from South Africa and RugbySmart from New Zealand use warm-up programmes as a form of training and match injury prevention (Gianotti, Quarrie, & Hume, 2009; Patricios, 2014). In this section, we review warm-up collision literature included in the BokSmart, RugbySmart, and World Rugby programmes.

According to du Toit (2009), as documented in the BokSmart for injury prevention, if coaches include collisions during their training sessions, the warm-up must also include collisions. The progression of a warm-up should be from a general and low intensity to a specific and higher intensity. The warm-up period should constitute 15 minutes of a one-hour training session (du Toit, 2009). BokSmart includes collision warm-up prescription guidelines focusing on training volume (sets and repetitions) for two collision drills. These guidelines require the athletes to make contact with one another in a gentle and controlled manner, including:

- buddy scrums - three scrums on each side (right and left) for six seconds each, coaches can also prescribe the exercise using a physio ball); and
- body neck tussles – four repetitions for six seconds each (BokSmart, 2019).

Since 2001, the RugbySmart injury prevention programme has included advice from top-level coaches, including All Blacks and Super Rugby coaches, providing instructions to players on technique in contact and conditioning; also, on anatomical and biomechanical simulations of injury mechanisms (Quarrie et al., 2020). The RugbySmart warm-up programme advocates for performance enhancement and injury prevention of rugby players of all ages by conducting warm-ups and strength and conditioning (New Zealand Rugby, 2018). Like BokSmart, RugbySmart highlights introducing contact slowly to the body and then progressively increasing intensity as part of the preparation for the contact phase; and practicing basic rugby movements and skills using simulated activities (New Zealand Rugby, 2023).

In the warm-up, strength, and conditioning sections RugbySmart advocates for neck strengthening including cheek-to-cheek exercises whereby the opponent places their neck against their partner's side-buttock area and pushes with their neck/head (New Zealand Rugby, 2023).

Lastly, the World Rugby Passport provides coaches with a 15-minute warm-up guideline for coaching children, including a three-minute preparation for contact phase, wrestling activities for children (six to nine years), and four minutes of specific strength speed and contact-based tasks at full intensity for children aged nine to 12 years (World Rugby, 2020b). While World Rugby mentions the duration of these contact drills, the specific frequency and volume were lacking.

Researchers recently conducted a systematic review and analysed nine studies involving national injury prevention programmes in rugby union using the RE-AIM framework (Barden, Bekker, Brown, Stokes, & McKay, 2020). Several national injury prevention programmes were reviewed, including BokSmart (South Africa) which addressed all (100%) of the dimensions on the RE-AIM checklist, and RugbySmart (New Zealand) which addressed 71% in comparison (Barden et al., 2020). While the primary focus of these injury prevention programmes was collision technique (i.e., tackling and scrumming technique), the specific exercise prescription parameters such as the volume, intensity, periodisation, and frequency of collision training and collision drills (i.e., tackle) were not provided (Gianotti et al., 2009; Patricios, 2014).

BokSmart and RugbySmart advocates for mandatory coaching courses before coaching players (New Zealand Rugby, 2018; South African Rugby, 2023). The websites include online written education, visual illustrations, and videos regarding injury prevention, tackling, and scrum techniques. These resources are freely available.

While BokSmart and RugbySmart do not include written information regarding collision skills using training simulated equipment such as a tackling bag, contact shield, or the scrum machine, it includes training videos regarding conducting collisions against players and tackling bags. These programmes provide online links to formal coaching levels one, two, and three by World Rugby (World Rugby, 2020a). While there is little research on collision parameters in rugby union, the following paragraph explains a wrestling study where researchers incorporated specific collision parameters (Bayati, Majelan, Mirzaei, & Barbas, 2019).

2.5.2 Collision Warm-Up in Wrestling

It is relevant to note that researchers have demonstrated the beneficial effects of a wrestling warm-up that includes three minutes of wrestling contact simulation. Researchers investigated the effectiveness of a 12-week (Wrestling+) warm-up programme on the Functional Movement Screen (FMS) scores in cadet wrestlers in Iran which included three minutes of contact wrestling simulation. Twelve cadet wrestlers were assigned to the intervention group and a further 12 were assigned to the control group (Bayati et al., 2019). The intervention group took part in the programme three times per week for 12 weeks, while the control group performed a standard warm-up during the study. The Wrestling+ programme consists of three parts and 14 exercises. The first part included eight minutes of running, grips, and bridges; part two included nine minutes of core, leg strength, and balance; and part three consisted of three minutes of wrestling stimulation. In the intervention group, there was a significant increase in the FMS scores with the deep squat, hurdle step, in-line lunge, and push-up, as well as a 66.7% decrease in the number of high-risk wrestles. There were no significant differences noted in the control group. While the inclusion of collisions during warm-up is a necessity for injury prevention, it must be highly controlled by the coach, who is required to place constraints on small-sided games and ensure general to specific collisions at a lower-than-game intensity, and at a 10 to 20-minute duration for an hour training session (du Toit, 2009; World Rugby, 2020c).

2.5.3 Prescribing Collision Training Using an Exercise Prescription Framework

Collisions are a requirement in different competition preparation spheres in collision sports, including both physical and technical conditioning (Gabbett et al., 2010). Athletes are required to endure and conduct collisions in rugby union, MMA, and boxing (Halperin et al., 2016; Kirk, Langan-Evans, Clark, & Morton, 2021; World Rugby, 2021). Coaches should consider prescribing collisions relative to the conditioning and technical skill requirements of the athletes (Hendricks et al., 2018). World Rugby recommends that coaches integrate collision technical/tactical skills into training by including small-sided games, game-related high-intensity interval training, and rugby-specific circuits to achieve rugby-specific conditioning (World Rugby, 2020c). Small-sided games include aspects of technical and tactical skills to achieve player conditioning through training adaptation and by the coach putting constraints on the game (World Rugby, 2020c). However, the collision activity during small-sided games was not documented (World Rugby, 2020c). Further, researchers have reported subjective methods of collision training prescription (i.e., RPE and the numerical contact intensity scale; Comyns & Hannon, 2018; Hendricks et al., 2019; Kirk et al., 2021).

2.5.3.1 Collision Training Volume

According to the fundamentals of resistance training, training volume is manipulated by altering the number of exercises performed per set, the number of repetitions per set, or the number of exercises per session (Kraemer & Ratamess, 2004). According to World Rugby, in the collision training context volume is defined as the number of contacts the athletes experience during a training session or a drill (World Rugby, 2021). Therefore, one can infer that manipulating the training volume in the collision context is similar to muscle resistance by specifically altering the number of exercises over time. In collision training, coaches may prescribe higher collision training volumes by increasing the number and repetitions of collisions during the drill or session (World Rugby, 2021).

2.5.3.2 Collision Density and Volume

Collision density is similar to training volume and refers to the frequency of collisions in a drill or training (per unit time) with the recovery during the drill (World Rugby, 2021). Coaches can prescribe higher collision densities by having athletes conduct frequent collisions with shorter recovery and inactivity periods, whereas coaches can also prescribe lower collision densities by having less frequent collisions with extended periods of recovery or inactivity with no collisions. Furthermore, high-density collisions can lead to injury. Therefore, collision training density should be measured and prescribed in connection to training volume as it includes the number of collisions athletes are exposed to over a period (Kraemer & Ratamess, 2004; World Rugby, 2021). Researchers encourage measuring volume by the amount of time an athlete engages in a drill or training that includes collisions. However, prescribing collision volume cannot be considered as a single variable. Volume is inversely related to intensity; therefore, as volume increases in training, the contact intensity should be maintained at a lower level (Kraemer & Ratamess, 2004).

2.5.3.3 Collision Intensity

Intensity is the degree or size of collisions in a session or drill (World Rugby, 2021). Researchers have separated intensity into full- and controlled contact (World Rugby, 2021):

a) full-contact intensity ranges between eight to 10 out of 10 on a contact intensity scale, where athletes complete the contact without physical restraint, and involves body-on-body contact, while
b) controlled contact is defined as contact below eight on the contact intensity scale, where athletes are restrained in terms of collision speed and force.

Researchers recommend measuring collision intensity by using a numeric zero to 10 rating scale, whereby coaches require athletes to rate the intensity with what they experience during a competition (World Rugby, 2021).

2.5.3.4 Collision Training Frequency

Researchers have defined frequency as the number of training sessions per week considered with the training volume, intensity, recovery ability, level of conditioning, training goals, and nutritional intake (Kraemer & Ratamess, 2004). In rugby union, the frequency of collision training is twice per week, with Monday and Friday being zero collision training days (World Rugby, 2021).

2.5.3.5 Collision Training Progression

Researchers have defined progression as the process of advancing toward a goal (Kraemer & Ratamess, 2004). In contrast, literature is scarce concerning collision training progression. With the application of collision training, World Rugby has suggested that there is no optimal structure for collision training during a given week (World Rugby, 2021). It has been recommended that rugby union coaches use their discretion to manage collision training while considering athletic recovery from matches (World Rugby, 2021). Therefore, the present dissertation aimed to gain the collision prescription perspectives of collision coaches.

In muscle resistance programmes, the subcomponents of progression include progressive overload, specificity, and variation (Kraemer & Ratamess, 2004). Progressive overload was described as the gradual stress increase placed on the body during exercise training. Coaches may alter progressive overload by increasing the load, repetitions, repetition speeds with submaximal loads, and volume. However, rest periods can be shortened or lengthened depending on the training goal, with shorter rest periods resulting in an increase in power and longer rest periods improving endurance. Concerning specificity, the most successful resistance training programmes are those designed to target specific goals (Kraemer & Ratamess, 2004). In collision training an example of exposing athletes to specific goals may include tackling and set-piece training.

However, these goals are conducted in an unpredictable environment during games, and therefore specific training goals should include unpredictable collision training. World Rugby defines collision unpredictability as the degree to which an athlete can anticipate their opponents' actions during collision events (World Rugby, 2021). Finally, variation or periodisation is the need to alter one or more training variables to achieve optimal performance. Systematically altering training volume and intensity is largely effective for long-term programme progression (Kraemer & Ratamess, 2004).

It is crucial that exercise prescription principles, whether in the muscle resistance or collision context, are prescribed together and not as separate entities (Kraemer & Ratamess, 2004; World Rugby, 2021). While these exercise prescription programmes have been theoretically tested in the muscle resistance setting (Kraemer & Ratamess, 2004), research on the collision training context is scarce and the literature does not report on collision progression or how these variables may change over the season (World Rugby, 2021). While prescribing collisions is crucial for injury prevention and conditioning, collisions during training are also a prerequisite to improving collision skills (Hendricks et al., 2018).

2.5.3.6 Collision Skill Training in Rugby Union

The uniform application of tactical periodisation is not recommended, as physical and skill development is the most successful when progressed from general to specific and when learning skills in isolation before linked and combined in complex sports situations (Tee, Ashford, & Piggott, 2018). Only a few frameworks exist for collision prescription. These frameworks are theoretical or based on small-group case studies (Table 5). A rugby union tackle framework has been proposed by Hendricks et al. (2018) and provides a five-week training programme for tackle development and skill measurement.

This tackling framework was established based on three skills training frameworks, including the constraints-based framework for skilled performance (a theory of motor learning and control; Davids, Button, & Bennett, 2008), the challenge point frameworks (the role of practice variables such as skill levels, task difficulty, and information theory concepts; Guadagnoli & Lee, 2004), and the skill acquisition periodisation framework (Farrow & Robertson, 2017) which emphasises the principles of physical training. Again, this is relevant as tackles are responsible for 50% of injuries in rugby union (Hendricks et al., 2018). Collision training requires athletes to collide with one another and this may lead to training injury. To minimise the effects of injury, coaches may prescribe training with protective equipment. The following section introduces protective equipment and focuses on protective headgear in team and individual sports.

Table 5. Collision Training Prescription in Elite Rugby Union, Mixed Martial Arts, and Boxing.

SPORT (AUTHOR)	STUDY TYPE & POPULATION	FREQUENCY	INTENSITY	VOLUME	DENSITY	DURATION
RUGBY UNION (World Rugby, 2021)	Expert Consensus- World Rugby Advisory Group on Contact Load	x2 weekly on a Tuesday and Thursday Zero contact on Monday's and Fridays	***Definition:*** The degree or size of collisions in a session or drill ***Full-contact*** Ranges between 8 to 10 out of 10 on a contact intensity scale, athletes complete the contact without physical restraint, and involves body- on-body contact ***Controlled contact*** is contact below 8, athletes are restrained in terms of collision speed and force	***Definition***: The number of contact the athletes experience during a training session, or a drill	The frequency of collisions in a drill or training (per unit time), in relation with the recovery during the drill Higher collision densities by having athletes conduct frequent collisions, with short recovery and inactivity periods whereas coaches can prescribe Lower collision density by less frequent collisions with extended periods of recovery or inactivity with no collisions	**15 minutes** full contact **30 minutes** live-set piece play **40 minutes**-controlled contact

Table 5 continued.

SPORT (AUTHOR)	STUDY TYPE & POPULATION	FREQUENCY	INTENSITY	VOLUME	DENSITY	DURATION
MMA (Kirk et al., 2021)	Cohort observational study design (n=14 competitive MMA athletes (n=7 preparing for a competition, and n=7 not preparing for competition) Observed over 8 weeks	Not reported	Training intensity distribution: High: 20% Moderate: 33% Low intensity: 47% The intensity was higher during midweek training than weekend training *High intensity* (RPE ≥ 7) = MMA and wrestling sparring Moderate intensity (RPE 5-6) = Striking sparring Low intensity (RPE ≤ 4) = Striking and BJJ drills Warm-ups had the lowest intensity of all the categories	Striking sparring (20-32%) weekly training load and wrestling displayed differences in load	Not reported	3-to-4 hours per week. Weekends have a *lower* training *duration* Significant difference in training *duration* in the final week of (n=7) competing MMA athletes

Table 5 continued.

Sport (Author)	Study Type & Population	Frequency	Intensity	Volume	Density	Duration
MMA (Amtman n, 2010)	Exploratory descriptive study Competitors from Montana, USA (n=32; Gender not specified)	*MMA specific training* 4-months from match- n=14 trained 2-3x/week 3, 2, and 1-month from match- most participants trained 4-5x/week	Not reported	Training *volume* and *frequency* terminology used interchangeably	Not reported	Not reported
BOXING (Halperin et al., 2016)	Case study: An Australian professional male boxer's 8-week title preparation	Preparation phase: 8-10 sessions per week Tapering phase (10 days before fight): 5 sessions per week	Intensity fluctuated between very high to very low. Tapering phase: intensity reduction Tapering phase: Technical focus, less emphasis on maximal training	Volume fluctuated between very high to very low Preparation phase: pad work, sparring, bag work, shadow boxing, and technical skills	Not reported	Not reported

2.5.4 Collision Training Prescription Using Protective Head Gear

2.5.4.1 Athlete and Coaches' Attitudes and Behaviours Toward Protective Headgear

For the present research, protective headgear is reviewed due to its relevancy in both team and individual collision sports, a brief review of protective equipment is included in Table 6. A systematic review by Tjønndal and Austmo Wågan (2021) highlighted a discrepancy between athletes' and coaches' attitudes toward protective headgear in sports. Athletes were from collision sports, including but not limited to Canadian and collegiate American rugby union, and non-collision sports such as skiing. While most athletes viewed headgear as protective against concussions and other facial injuries, relatively few wore them primarily due to discomfort and poor appearance. For example, while 62% of the 63 (female and male) Canadian rugby union players believed wearing headgear could prevent concussion, only 27% wore them. In contrast, only 33% of Canadian rugby union coaches stated that using headgear protected against concussion. Tjønndal and Austmo Wågan (2021) recommended that additional studies examining coaches' and athletes' attitudes and behaviour would be required to improve concussion culture in sports.

2.5.4.2 Headgear in Boxing

A systematic review by Tjønndal, Haudenhuyse, de Geus, and Buyse (2021) aimed to determine whether there were increased injury risks associated with head-guard use in Olympic boxing. The researchers reviewed 39 articles, with only three having included females. The inclusion criteria were studies investigating junior, youth, elite, recreational, or competition boxers. The authors concluded that headgear significantly protected against lacerations and skull fractures; however, the protective effects of headgear on concussions were uncertain (Tjønndal et al., 2021).

Table 6. Protective Sports Equipment in Collision Sports.

SPORT	PROTECTIVE EQUIPMENT AND REFERENCE
RUGBY UNION	• Mouth guard - Protect against orofacial injuries (Daneshvar et al., 2011). • Headgear- to prevent abrasions and laceration; no concluding evidence suggesting concussion prevention (BokSmart). • Compression garments- Potentially reducing sprains and strains and preventing the hamstring injury recurrence (BokSmart). • Shoulder pads- Used as injury prevention, against bruising cuts, and abrasion (Hughes, Carré, & Driscoll, 2021); absorb and disperse force from direct impact contact (BokSmart).
MMA	MMA athletes wear a mouthpiece, a groin or a chest protector for male or female athletes, and 4 ounce gloves (Spanias, Nikolaidis, Rosemann, & Knechtle, 2019).
BOXING	• During the 1960s and 1970s, the use of mouth guards was made mandatory in boxing (Daneshvar et al., 2011). • Head-guards- protect against lacerations and skull fractures. It does not protect against concussion (Tjønndal & Austmo Wågan, 2021). • Boxing gloves only resulted in forces below the concussion level (588N for 26s) on the first few impacts. Peak impact force doubled by the 50th trail (1484N to 2913N) and enhanced punching collision forces with prolonged glove use (Smith & Hamill, 1985).
AMERICAN FOOTBALL	Custom fitted mouthguards/dental orthotics- might be more effective at measurably absorbing the force of impact (Daneshvar et al., 2011).

2.6 Literature Review Conclusion

The tackle in rugby union is the most common cause of injury; similarly, strikes to the head in MMA and boxing. Due to the damaging nature of these collisions, the injury burden during competition matches is the highest (Kay et al., 2017; Williams et al., 2013). Similar injury diagnoses and injury sites were observed for rugby union, American Football, and wrestling (Kay et al., 2017; Thomas & Thomas, 2018; Williams et al., 2013); also, there were similar injury diagnoses and injury sites for MMA and boxing (Lystad et al., 2014a; Thomas & Zamanpour, 2018; Zazryn et al., 2009). According to Krill et al. (2017), future injury prevention studies in American Football should evaluate the individual athlete and the contact exposure type (including full, semi, or no contact). While the injury burden during training is lower than during a match (Kay et al., 2017; Williams et al., 2013), training collisions are a necessity for match preparation (Hendricks et al., 2018).

When planning and prescribing collisions during training, coaches must understand the different exercise prescription variables such as collision volume, density, intensity, frequency, progression, and periodisation (Abraham et al., 2014; Kraemer & Ratamess, 2004; World Rugby, 2021). These variables are interrelated and when prescribing a more significant amount of one, the coach should consider its impact on the other variables (e.g., when increasing collision intensity, the volume should be decreased; Kraemer & Ratamess, 2004). During a one-hour training session in rugby union focused on collisions, a warm-up should be included for 15 minutes of that hour, of which three to four minutes should be allocated for player-against-player collisions such as wrestling, buddy scrums, body neck tussles, and cheek-to-cheek tasks (BokSmart, 2019; New Zealand Rugby, 2023; World Rugby, 2020d). Further, there should be a gradual progression of collision tasks during the warm-up from general and low intensity to specific and high intensity (du Toit, 2009; World Rugby, 2020d).

Monitoring collision training is critical to ensure the safety and performance of the athlete, which requires coaches to track the athletes' internal load such as heart rate and RPE (Schwellnus et al., 2016) and understand the biomechanics of collisions for external loads (Whiting & Zernicke, 2008). Global Positioning Systems provides a non-bias measurement of external load of collision activity (frequency) in rugby league (Gabbett, 2015). However, its efficacy in individual sports such as MMA remains inconclusive (Kirk et al., 2020). More specifically, future intervention studies for measuring and monitoring collisions and muscle damage require larger sample cohorts and interventions with more specific muscle damage effects. These studies would allow researchers to monitor and measure muscle damage across its various stages (Järvinen et al., 2005; Smith et al., 2008). Additional intervention studies on IIMD would further allow for a better understanding of the effect of sports collisions (tackling, striking, and grappling) on the body, thereby improving collision training prescription.

The present study aims to explore the perspectives of elite collision coaches concerning collision training prescription. According to researchers, it is essential to describe collision prescription parameters such as frequency, intensity, and duration to improve collision training (Hendricks et al., 2017). Chapter Three highlights the practicality of using a qualitative research approach to research exercise-prescription parameters such as frequency, intensity, duration, and collision activity as reflected in the collision training and to describe differences in collision prescription across different collision sports.

CHAPTER THREE: METHODOLOGY

3.1 Theoretical and Methodological Approach

According to Slade, Patel, Underwood, and Keating (2018), "qualitative research enables inquiry into processes and beliefs through the exploration of narratives, personal experiences, and language" (p. 1). We therefore used a qualitative descriptive study design to explore coaches' perspectives of collision training. Researchers have used a qualitative descriptive study when describing perceptions in areas where little is known (Doyle, McCabe, Keogh, Brady, & McCann, 2020). Given the scarcity of literature concerning collision training prescription, we used methods enabling explorative and descriptive elements. We also aimed to describe collision prescription variables like frequency, intensity, duration, type, and volume; and describe differences in collision prescription between the participants. These theories of training prescription formed the basis of our inquiry as coaches prescribed these principles to athletes during training.

Qualitative descriptive designs draw from naturalistic inquiry embedded in the constructivist paradigm (Lincoln & Guba, 1985). Naturalistic inquiry means studying something in its natural setting (Lincoln & Guba, 1985). Therefore, we aimed to conduct an international study and interview multinational coaches to explore collision training prescription. Constructivism is an understanding that all knowledge and reality rely upon human practices when interacting with one another and their world, establishing and transmitting their reality in a social context (Crotty, 1998). Therefore, we adopted a constructivist paradigm as coaches often have multiple roles within the sports setting (Olusoga, Butt, Hays, & Maynard, 2009). The research setting was an international study consisting of multinational participants. We used the COnsolidated criteria for REporting Qualitative research (COREQ) checklist (Tong, Sainsbury, & Craig, 2007)(Appendix A).

3.2 Participants

3.2.1 Inclusion Criteria

Elite collision coaches were operationally defined as those participating at a national or international level, professional league, or university-level competition in their respective sports (Swann et al., 2015). The participants were required to have coached within the previous five years in an elite collision- sports setting and to have been responsible for prescribing collision training in a professional sports environment. The five-year period ensured that coaches were up to date with the latest rules in their sports, and that they have had experience prescribing collisions. The selected coaches were required to be proficient in English to ensure they understood the interview questions.

3.2.2 Exclusion Criteria

Coaches who did not provide informed consent were excluded.

3.2.3 Sampling and Recruitment

Purposeful sampling was used as the initial sampling strategy. According to Guest, Bunce, and Johnson (2006), purposeful sampling is when participants are selected based on predetermined criteria relevant to a particular research objective. More specifically we used purposive maximum variation sampling to explore different perspectives of collision training prescription (Palinkas et al., 2015). Also, Breckenridge and Jones (2009) stated that the researcher must have some idea of where to sample, not necessarily what to sample for, or where it will lead. We identified the coaches based on their expertise in the collision sports setting and based on historical professional relationships. We had prior research encounters with all coaches from rugby union, and direct or indirect practical training encounters with the MMA coaches. The boxing coach was randomly identified through the University Sports South Africa. Furthermore, purposeful sampling provided rich, relevant, and diverse data to answer the research questions (Tong et al., 2007).

We recruited six elite male collision coaches (three from rugby union, two from MMA, and one from boxing; see Figure 2 below). More specifically, we recruited three South African and three international coaches from different collision sports backgrounds. The narrow scope of collision sports is due to the purposeful sampling strategy to obtain rich information. We selected these collision sports codes as they are established in the South African and international context (Hendricks et al., 2018; Venter et al., 2017). After six interviews, we stopped recruiting participants as all concepts were well defined and explained and there were no new developing themes from the interview data collection, indicating that data saturation had been reached (Bluff, 2005; Guest et al., 2006). While researchers have described that reaching data saturation may be linked to a specific number of interviews, these findings remain inconclusive (Guest et al., 2006).

Also, researchers have suggested that reaching data saturation depended on the complexity of the data, researcher experience and fatigue, and the number of analysts reviewing the data (Ryan & Bernard, 2003). Sample size policy for qualitative studies using in-depth interviews recommend anywhere between 5 and 50 interviews (Dworkin, 2012). Other qualitative interview studies have included as few as five elite coaches (Callinan, Connor, Sinclair, & Leicht, 2023). However, researchers do highlight fewer qualitative studies (at least six) for a homogenous group, rather than a varying group of participants (Guest et al., 2006).

Following the identification of potential participants, the participants were recruited via various methods. In some instances, we had historical professional relationships with coaches who met the inclusion criteria and were invited to participate in the study via email or social media (see Appendices B, C, and D). In addition, we contacted sports organisations (e.g., Boxing South Africa – Appendix E) via their publicly listed contact details by email or telephonically. We obtained further guidance from sports organisations on how to contact their coaches. We then contacted these coaches telephonically or via WhatsApp message to secure an interview date and time.

3.2.4 Semi-Structured Interview and Interview Guide Development

We conducted a pilot interview in September 2021 using qualitative interview techniques obtained at an undergraduate and postgraduate university level. We included the pilot interview data as interview one in the present results. Two authors (one having a PhD in Sports Science and the other a Physiotherapist) and one participant were present during the pilot interview. We conducted a pilot study to improve the credibility of our qualitative dissertation (Kim, 2011).

We initially conducted the pilot interview using the pilot interview guide (see Appendix F). Then following the pilot study, we amended the interview guide to include questions more specific to collision training prescription principles (Appendix G). Following the pilot interview, we conducted one-on-one semi-structured interviews between one author (Physiotherapist) and one participant until December 2021. The average interview length across the six interviews was 52 minutes. The longest interview had a duration of one hour, and the shortest, 42 minutes.

The interview guide was specific to collision sports prescription and was developed based on expert knowledge of collision sports by the supervisor, interviewing skills, and feedback from the pilot interview. The interview guide was further developed by considering the grounded theory approach (that questions should not be based on the interviewer's preconceived ideas) and expanded the discussion, allowing us to follow various avenues of inquiry (Harper & McCunn, 2017).

The interview guide consisted of four sections: Section One comprised of an introduction, wherein we outlined the interview's purpose, as well as issues related to confidentiality and general demographics. Section Two took the form of a warm-up and was used to build rapport (Patton, 2002) by inviting participants to expand on their educational and occupational journeys in elite coaching. The third section comprised most of the interview and focused on collision training prescription.

Section Four comprised of a cool-down where the participant's views were summarised, allowing them to add additional information. Finally, we closed the interview with a discussion regarding the potential need for a follow-up interview (Rubin & Rubin, 2012); and asked the participants whether they knew of any potential recruits. Although we attempted snowball sampling, the potential recruits did not provide consent.

3.3 Research Procedure

We obtained ethical approval from the Human Research Ethics Committee (HREC; Reference number 450/2021) from the Faculty of Health Sciences at the University of Cape Town (Appendix H). The qualitative dissertation was ethically approved for us to explore elite coaches' perspectives of collision training prescription. Following ethical approval, we conducted an in-depth pilot interview using the developed interview guide and qualitative questioning techniques appropriate to qualitative descriptive dissertation. Thereafter, we sampled and recruited participants as described in the sampling and recruitment section below.

All participants, including the pilot interviewee, were required to read and complete the online informed consent Google Docs form before participating in the study (Appendix B). The consent form was easily distributed to the participants via an online link, accessible via email, WhatsApp, and social media platforms. The consent form explained the purpose of the study and outlined what participation would entail. The consent form also allowed participants to choose whether they agree to participate and allowed them to provide a date and time convenient to them. Following the completion of the informed consent form we commenced the online Zoom interviews (Figure 2), by sending a Zoom link to the participants.

We collected primary data via an online Zoom video recording between ourselves and the participants. Data collection occurred once the interviews commenced and through follow-up meetings with most participants (n=3) via varied sources (Twitter, WhatsApp, and telephonically). Following data collection, we transcribed the interviews using a secure transcription company and coded the data to form themes using the NVivo 12 software.

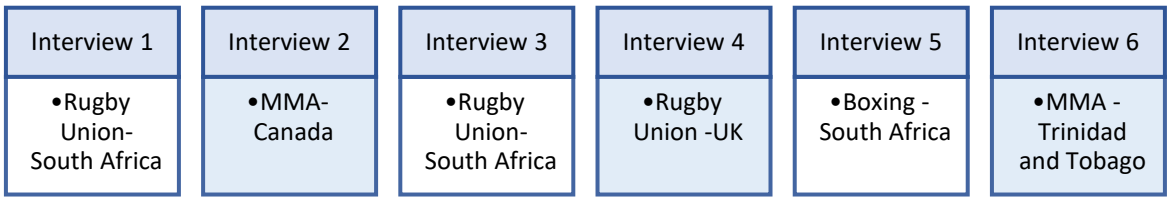

Figure 2. Zoom interviews.

3.4 Data Collection via Semi-Structured Interviews

We used the Zoom online platform to conduct semi-structured in-depth interviews. "In-depth interviews is one of the most valuable techniques for truly understanding the richness of another person's perspective" (Côté, 1993, p. 52). We also collected and recorded audio and visual data and stored the data on a local, password-protected computer. The data was shared between three authors via Google Drive. The interviews were transcribed by a secure transcription company (www.ontimetranscribers.co.za).

Thereafter, we (three authors) analysed the interview data using thematic inductive analysis (see Section 3.5) and grounded theory within the NVivo version 12 (QSR International Pty. Ltd) qualitative computer software. The NVivo12 software enabled the organisation and analysis of the qualitative data. We discussed emerging data and themes. When we used thematic analysis and grounded theory, the data collection and analysis were not separate but intertwined and interdependent (Braun & Clarke, 2006; Vollstedt & Rezat, 2019).

3.5 Data Analysis and Coding using Inductive Thematic Analysis and Grounded Theory

Our approach to data analysis and coding was thematic analysis as we aimed to identify themes within our data through coding. “Thematic analysis provides a flexible and useful research tool, which can potentially provide a rich and detailed, yet complex, account of data” (Braun & Clarke, 2006, p. 78). Specifically, we used an inductive approach in the qualitative dissertation. According to Braun and Clarke (2006) an inductive approach means that the themes identified link to the data. Correspondingly, the coaches’ perspectives concerning collision prescription during training drove the data collection in the semi-structured interviews. Further, Braun and Clarke (2006), stated that inductive analysis is a process of coding data without trying to fit it into a pre-existing coding frame or the analytic preconceptions of the researcher.

We used the grounded theory approach to help gather, analyse, and synthesise data (Bolling, Barboza, Van Mechelen, & Pasman, 2020). The grounded theory approach provided a set of procedures, including inductive analysis, that kept the data analysis close to the data and provided inductive discoveries regarding the collision prescription. Further, this allowed information to stem from the participants' perspectives, requiring us not to impose preconceived ideas on the data. We used two levels of analysis in grounded theory: firstly, to present the data without interpretation and abstraction and have the participants tell their own stories; secondly, to create a rich and believable descriptive narrative using field notes, interview transcripts, and researcher interpretation (Lawrence & Tar, 2013). We used three coding steps from grounded theory: open coding, axial coding, and selective coding (Strauss & Corbin, 1998).

3.5.1 Open Coding

Open coding is the first step of grounded theory and was used to create codes based on the repeated ideas and elements extracted from the data (Bolling et al., 2020). In this first step of coding, we remained open to exploring theoretical possibilities from the participants’ data (Charmaz, 2006).

Themes and sub-themes were employed when similar events and/or incidents were noted. The data was coded as actions instead of applying pre-existing categories (Charmaz, 2006). According to Charmaz (2006), coding data as actions is essential to curb ideas before progressing to any analytical work. We employed coding with gerunds, as stated by Glaser (1978). Coding with gerunds uses verbs ending in *-ing* instead of their noun form (e.g., describing instead of description; Charmaz, 2006). Using gerunds encouraged us to analyse data from the participant's perspective (Charmaz, 2006). Further, line-by-line coding was used, naming each line of the written data. This method allowed us to remain open to the data and see its variation (Charmaz, 2006). The initial coding practices were applied as stated by Charmaz (2006) and included: remaining open, keeping codes simple and precise, comparing data with data, and moving quickly through the data.

3.5.2 Axial Coding

Axial coding enabled data rebuilding and established relationships between categories (Lawrence & Tar, 2013). It linked categories to subcategories as properties and dimensions (Strauss & Corbin, 1998). We developed subcategories and demonstrated links between them as we learned about the experiences the categories represented. Constant comparison was employed by comparing different categories and identifying data variation (Lawrence & Tar, 2013).

3.5.3 Selective Coding

This final coding process integrated and refined the data to develop a theory. It allowed us to reduce data into concepts and rationale statements, explaining what was occurring (Strauss & Corbin, 1998). The coding process continued until data saturation was obtained. Additionally, theoretical sensitivity enabled the formulation of a theory. It allowed us to use our personal and professional experience and methodological knowledge to understand data in new ways and to think abstractly (Hallberg, 2006).

3.6 Data Rigor and Trustworthiness

Four elements were used to establish trustworthiness. This included credibility, transferability, dependability, and confirmability (Shenton, 2004).

3.6.1 Credibility by Triangulation, Member-Checking, and Reflexivity

Credibility was established by methods of triangulation, member-checking, and reflexivity. We used triangulation of data sources (participants from different collision sports) and investigator triangulation (including more than one researcher during the online interview and data analysis/coding) to decrease bias in gathering, reporting, and analysing data (Rugg, 2010).

Member checking was performed to ensure that the participants' meanings and perspectives of what they said were represented and not curtailed by our own perspectives (Tong et al., 2007). Accordingly, we presented the transcribed data to participants to confirm whether the concepts captured were an accurate reflection of their thoughts. Also, we had a second contact point with three out of the six coaches to obtain data saturation and further data clarification.

Credibility was improved using reflexivity (Engward & Davis, 2015). According to Schwandt, as stated by Engward and Davis (2015), reflexivity was defined as the process of critical self-reflection on one's biases, theoretical predispositions, and preferences while acknowledging that the enquirer is part of the setting, context, and social phenomenon they seek to understand. We applied reflection by self-reflecting after each interview, acknowledging the enquirer as part of a social construct.

3.6.2 Transferability Through Thick Description

Transferability was established by using thick descriptions in explaining the behaviour, experiences, and context of the coaches (Korstjens & Moser, 2018).

Thick description was applied by adhering to participant anonymity and protection, and not describing any irrelevant details (Breckenridge & Jones, 2009). Therefore, transferability would be enhanced by sharing the dissertation findings with the participants, other coaching communities, and the scientific community via open-access online platforms and respective sports organisations.

3.6.3 Dependability and Confirmability Through an Audit Trail

An audit trail was used to enhance dependability and confirmability and included a transparent description of the research steps from the start to the development of the research findings (Korstjens & Moser, 2018). Furthermore, an audit trail aided in confirmability through careful coding and memo writing that was investigated towards the end of the research process (Feeler, 2012). To further enhance confirmability, a pilot study was conducted.

3.7 Ethical Considerations

Ethical approval was obtained from the Human Research Ethics Committee of the Faculty of Health Sciences at the University of Cape Town (HREC Ref: 450/2021; Appendix H) and adhered to the general principles, risks, burdens, and benefits outlined in the Declaration of Helsinki (World Medical Association, 2013). We declared no conflict of interest and participant reimbursements in this dissertation.

3.7.1 Confidentiality, Risks, and Privacy Through Data Storage and Participant Anonymity

We notified participants about the risks, in the informed consent form and during the interview, that their privacy and confidentiality may be limited and identifiable, as quotes from the participants would be used in presenting the research findings. Following the recorded Zoom video interview, the data was stored on a password-protected computer. We ensured participant protection by protecting the confidentiality and anonymity of participants.

All interviews was anonymized as the participants were given pseudonyms instead of using their names (Creswell & Poth, 2016). Further, there were no risks, burdens, or maleficence associated with taking part in the study.

3.7.2 Autonomy and Justice

Autonomy and justice are basic ethical principles that may alleviate difficulties in qualitative research by awareness and application within a study (Creswell & Poth, 2016). Autonomy was adhered to by informing participants that they have the right to withdraw from the study at any time without prejudice and that their participation is voluntary. Further, we applied respect for the participant's autonomy and justice through informed consent. According to Orb, Eisenhauer, and Wynaden (2000), in qualitative research autonomy is honoured by informed consent and includes balancing, overinforming and under informing participants. Therefore, to better elaborate on patient autonomy and justice, we obtained informed consent. Researchers define justice as fair, equitable, and appropriate treatment of persons (Varkey, 2021). We applied justice by including coaches from various collision sports and contexts.

3.7.3 Social Value and Benefits

We will distribute the results of the dissertation to the participants. The dissertation and study results will be made freely available via an online open-access platform for coaching and scientific members. This dissertation may impact collision sports by highlighting how and why coaches prescribe collision training. There were no direct benefits or beneficence to individual participants in this research. However, the participant may benefit from the interview by engaging in 'sensemaking' around their contact prescription practices. The advancement of tacit or procedural coaching knowledge to declarative coaching knowledge through 'sensemaking' activities is a recognised form of professional development for coaches (Abraham & Collins, 2011).

CHAPTER FOUR: RESULTS

From the qualitative analysis, three main themes emerged related to collision training prescription by elite coaches. The themes and subthemes explored are presented in Table 7 below. A summary of the coaches' characteristics follows in Table 8.

Table 7. Three Themes and Related Sub-themes Identified During Qualitative Analysis.

THEMES	SUB-THEMES
THE DEVELOPMENT AND PROGRESSION OF COACHING EXPERTISE	• Describing the sample characteristics

PLANNING COLLISION TRAINING	• The necessity of collision training
	• Developing skills in novice and elite athletes
	• The collision training environment
	• Prescribing collision training based on exercise prescription principles:
	  ○ Exercise specificity for collision training
	  ○ Collision training volume
	  ○ Collision training intensity
	  ○ The duration of collision training sessions
	  ○ The frequency of collision training sessions
	  ○ Periodisation of collision training in proximity to the competition

ADJUSTING, MONITORING, AND MEASURING COLLISION TRAINING	• Adjusting collision training
	  ○ Collaborations across diverse sporting specialties
	  ○ Protective equipment
	  ○ Training simulation: collisions against protective equipment versus live collisions
	• Measurement in collision training
	• Mitigating injury risk during collision training
	• How collision training has changed over time

4.1 The Development and Progression of Coaching Expertise

In this theme, we described the characteristics of elite coaches (Table 8). We highlighted their previous athletic experience, ongoing formal education, and informal coaching learning to understand the coaches' collision training perspectives. This section links to the objectives of the dissertation by exploring the roots of the coaches' collision training and by describing the differences between them.

4.1.1 Describing the Sample Characteristics

All coaches from rugby union had specific roles. P1 coached forwards in rugby union, P3 coached the backline in rugby union, and P4 was a rugby union strength and conditioning coach. For combat sports, P2, P5, and P6 were responsible for both developing collision technique and strength and conditioning. The coaches all received their expertise from past athletic experience in their respective sports. Although most coaches obtained formal coaching qualifications specific to their sport's planning, they lacked formal qualifications related to the prescription of collision training. In contrast, most of the included coaches learned about collision training prescription from informal sources, such as other coaches. While six elite coaches were included, two coaches were excluded as they did not provide consent, and one coach was excluded due to technological faults. The excluded participant did not have stable internet connection and could not join the online Zoom meeting. All included coaches highlighted playing their respective sports before becoming a coach (Table 8). Therefore, we highlighted the athletic experience of the coaches. The coaches better understood their profession by developing their own athletic skills and experiences. While the included coaches from rugby union mentioned playing rugby as former elite international or elite club competitors, the MMA and boxing coaches participated at amateur competition levels. Further, the MMA coaches also participated in other martial arts, including karate and judo, before competing as MMA athletes.

The elite coaches held academic and sports qualifications which formed part of their coaching expertise - the range of qualifications varied, with half of the participants possessing tertiary-level education. Coaching participants also held qualifications related to their respective sports, highlighting their eligibility to coach at an elite level. However, few qualifications were explicitly related to collision prescription. The academic and coaching qualifications of coaches were similar for rugby union. The three rugby union coaches all possessed rugby-specific education from World Rugby (levels 1, 2, and 3) and had each obtained a bachelor’s degree.

While one of the rugby union coaches had obtained a master's degree in sports science related to rugby performance improvement, the other two rugby union coaches were currently pursuing their master's degrees in branches of psychology, which they felt would benefit their rugby union coaching ability towards athletes.

In contrast, both MMA coaches did not possess any tertiary-level qualifications; however, they were skilled in the sport, having sport-specific belt gradings. Similarly, P6 had no tertiary qualification but was certified as a Star One Accredited South African Boxing Coach, allowing him to coach South African boxers internationally. Most coaches emphasised learning from informal sources, such as other coaches, their former clubs, and via informal methods such as WhatsApp groups, telephone conversations, and video material. Following Table 8, the second theme of the results concerning planning collision training is introduced.

Table 8. Coaches Demographics.

PARTICIPANT & SPORT	COUNTRY	ATHLETIC EXPERIENCE	COACHING EXPERIENCE (YEARS)	FULL OR PART-TIME	LEVEL OF COACHING	ACADEMIC AND SPORTS QUALIFICATIONS	INFORMAL COACHING LEARNING
P1 RUGBY UNION	South Africa	*"I played under 21 for [university] and [name of club], so I then played professional rugby since 1996…became an [international player] then…I went to [name of country] and played for [name of international club] …"*-P1	>10	Full-time	Elite club, high school	*"I'm busy with my master's in psychology and counselling…"*-P1 *"I've done level 1,2 and 3 and you learn a lot and I think that it's good, but you don't learn rugby stuff, you learn the methodology or you learn how to plan off season, those kind of things."*-P1 *"…there's no book that teaches you this is the scrum rules."*-P1	*"I'm part of a scrum group on WhatsApp where it's scrum coaches from the premiership in [country a], guys from in [country b] and in [country c] that some of them I played with, and we sometimes throw a video clip on and say hey boys what do you think of this, is this good or bad, so it's a very open share, most of them have played prop in their lives…"*-P1 *"There's a lot of people that I phone, from medical doctors to conditioning coaches, to try to understand...stuff that I've never heard as a player...like what position should my back be..."*-P1

Table 8 continued.

PARTICIPANT & SPORT	COUNTRY	ATHLETIC EXPERIENCE	COACHING EXPERIENCE (YEARS)	FULL OR PART-TIME	LEVEL OF COACHING	ACADEMIC AND SPORTS QUALIFICATIONS	INFORMAL COACHING LEARNING
P2 MIXED MARTIAL ARTS	Canada	*"I stopped karate and entered into MMA training, I was 21 years old, and now it's been about 15 years that I'm training at [name of the gym], I became a coach now… "… I'm a black belt in Jiu-Jitsu, and I've been training boxing and Muay Thai for just as long as I've been training jujitsu."*-P2	>10	Full-time	Elite club	Black belt in Jiu-Jitsu	*"I train with the best coaches who train with all the best coaches all over the world and I take what they teach me, a lot of the times I used to write it down and now I just I remember it, I go back and I look in my notes and I watch videos, I do my research on fighters and that's basically it, my trick is I never stop training, I never stop training myself."*-P2

Table 8 continued.

PARTICIPANT & SPORT	COUNTRY	ATHLETIC EXPERIENCE	COACHING EXPERIENCE (YEARS)	FULL OR PART-TIME	LEVEL OF COACHING	ACADEMIC AND SPORTS QUALIFICATIONS	INFORMAL COACHING LEARNING
P3 RUGBY UNION	South Africa	*"…I was playing junior rugby for [name of the university and elite club]…"*-P3	>10	Full-time	Elite club, high school	*"I'm busy with my masters in industrial psychology…I'm sure that it will be helpful in terms of understanding team dynamic… I think that part of the degree will probably help some towards the coaching."*-P3 *"…think it's called World Rugby, it used to be the IRB level 1,2 and 3 on the coaching side…"*-P3	*"...each union has got it's ways of doing things, when I was at the [name of former club] a lot of my career was done with the junior system, so we were prescribed to, by the guys at the senior level, how quick they want sessions or what sort of sessions you should have on a Monday, Tuesday and a Thursday. We used that as a framework to work off of and then obviously when you get to the senior side, then you get the opportunity to sort of tweak that...also having moved over to a new club, it was about adapting to their week's schedule... learning to set up coaching training sessions using the specific coaching club framework and philosophy."*-P3
P4 RUGBY UNION	Wales	*"I spent most of my adult life as a professional rugby player, so I understood the game…"*-P4	>15	Full-time	Former international and elite club. Retired from rugby coaching since 2021	*"I did a second masters in sports science, that one was a master of philosophy research degree where I looked at using machine learning and statistics to try to predict the most important key performance indicators in premiership rugby matches."*-P4	

Table 8 continued.

PARTICIPANT & SPORT	COUNTRY	ATHLETIC EXPERIENCE	COACHING EXPERIENCE (YEARS)	FULL OR PART-TIME	LEVEL OF COACHING	ACADEMIC AND SPORTS QUALIFICATIONS	INFORMAL COACHING LEARNING
P5 MIXED MARTIAL ARTS	Trinidad and Tobago	*"I stopped at a brown belt in Judo…I started MMA in 2007, I did about six fights…Then I trained many professional fighters."*-P5	>15	Full-time	Elite club	Brown belt in Judo	
P6 BOXING	South Africa		>15	Part-time	International, provincial, university, community	*"…there is level one, level two, level three. When you done with that you go and get a star, that means international recognition. So it works like that… you register under the boxing federation. The federation will empower you to get the necessary skills to become a coach."*-P6	

4.2 Planning Collision Training

4.2.1 The Necessity of Collision Training

Coaches identified different constructs to explain the necessity of collision training, such as conditioning the athlete's body and simulating game or competition-day conditions (Figure 3). Across all sporting disciplines, coaches placed significant emphasis on simulating the conditions of the game and less significance on conditioning the player's body during training to meet the demands of the game. Coaches considered collision training to be a form of game simulation and should be simulated as close to the actual game as possible, but that player injury should be avoided. Also, one coach mentioned the required intensity at which training simulation would commence: "*You will get the intensity as close as they will be feeling in a fight but without the actual trauma."* -P5.

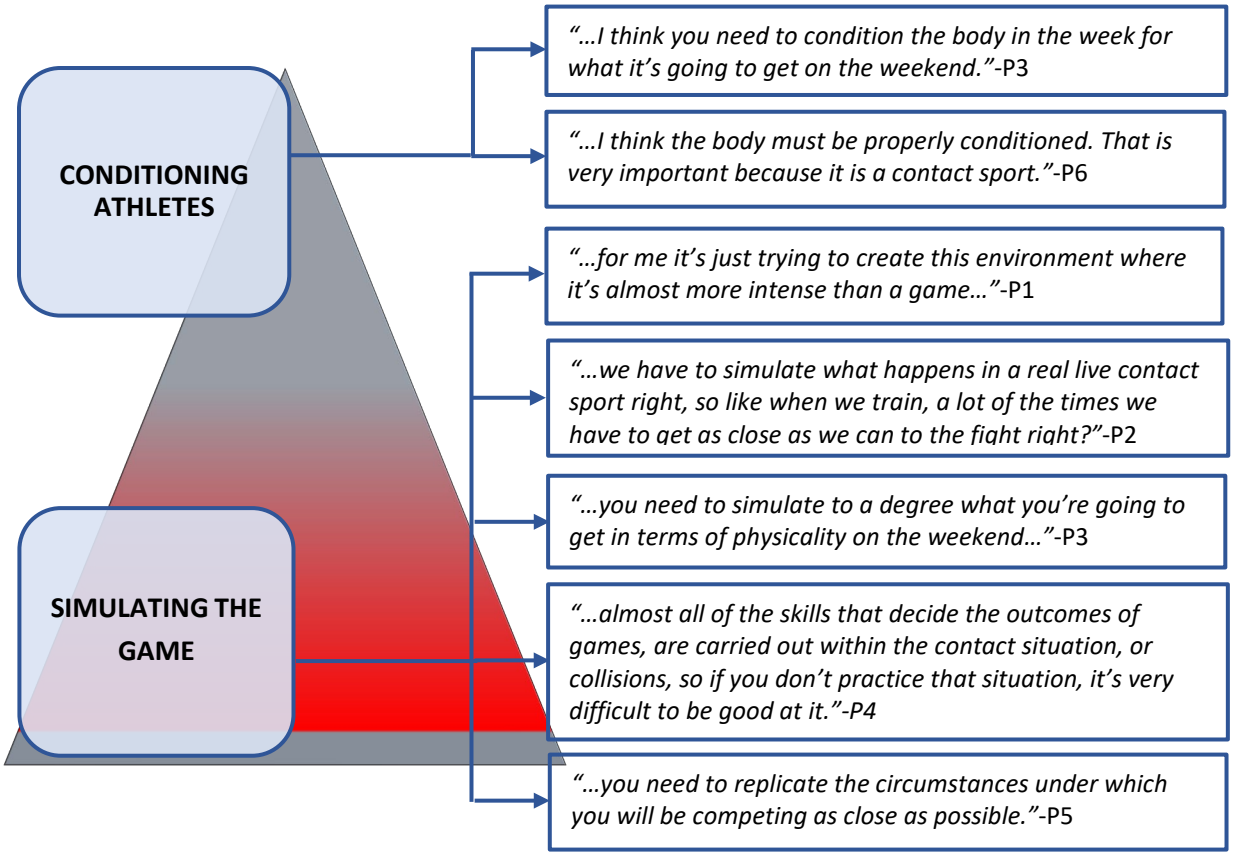

Figure 3. Quotations from elite collision coaches for the sub-theme 'The necessity of collision training.'

4.2.2 Developing Collision Skills in Novice and Elite Athlete

Elite coaches varied their collision training prescription according to the athlete's experience (i.e., elite or novice). Novice athletes required significantly more collision prescriptions related to education on collision technique, avoiding specific techniques, and protective equipment (Table 9). Similarly, elite athletes were also required to wear the correct protective equipment. In contrast to novice athletes, coaches were less restrictive with elite athletes, allowing them more freedom to use advanced collision techniques. Coaches also utilised elite athletes to teach novice athletes collision training (Table 10).

Table 9. Quotations from elite collision coaches for the sub-theme 'Prescribing collision training based on exercise prescription principles.'

EXPERIENCE LEVEL	QUOTATION
NOVICE	*"I've got to be able to teach under-14's that's never heard a word of rugby…I'm part of a high school system, teaching all the guys, understanding what's posture and shape, not only the forwards but it'll be ideal if you can get to the backs as well, but it's sometimes difficult, but understanding how to create body posture."*-P1
	"…so they're still beginner right, so they don't even know what they're doing a lot of the time, sometimes they're so beginner and they'll just turn in…like they'll throw it and there's nothing that could stop that, so the only thing that could stop it is if you have to have the coach watching…"-P2
	"…there are certain moves that we've taken away from beginners right, so there are certain moves we're only allowed to use when we're more advanced."-P2
	"With amateur athletes' protective equipment is 80% for building confidence related to tackling technique and injury prevention."-P3

Table 10. Quotations from elite collision coaches for the sub-theme 'Planning collision training.'

EXPERIENCE LEVEL	QUOTATION
ELITE	*"The more advanced guys, they're allowed to go a little bit harder to the body and to the legs, but still no big shots to the head. For the more pro guys, it's pretty much anything goes but they have to wear protective equipment."*-P2
	"We use protective equipment to spare the elite players' bodies for the weekend."-P3
	"…each player will have a varying mixture of that which makes them an elite player and the guys that get to the top probably have pretty high physical, technical, and psychological levels, so it would depend on the level that you're playing at."-P4
	"So moving forward, I realised elite training is going to be a very small group of five people most in the class. I can really spend the time to focus on the time and strategy. -P5
	"Usually we take the advanced boxer to actually spar with the one that doesn't have that kind of experience. So he will show the mistakes. That's why it is advisable you take the advance technical boxer to spar with the one that is on a lower level."-P6

4.2.3 The Collision Training Environment

A few coaches had divergent views on whether the environment in which athletes conducted the collision task was unpredictable or predictable. However, the coaches consistently implemented control elements such as explaining the task beforehand, ensuring the use of protective equipment, and observing collision tasks during the session:

- *"Just like in a real fight, we do situational stuff where it's unpredictable, but it's still under a controlled environment with pads on, an instructor, and controlled strikes"-P2.*
- *"I do not think we can use the word unpredictable because when we enter the session, we make it quite clear the level of contact is required, so there's clarity at the front-end of the session of what needs to happen, and I think that gives control…"-P3.*

4.2.4 Collision Training Based on Exercise Prescription Principles

4.2.4.1 Exercise Specificity for Collision Training

All coaches integrated sports-specific training components, apart from prescribing collisions, during each collision training session (Table 11). Participants had diverging views on the specific exercises they selected for collision training sessions. To prepare players for collisions, coaches from rugby union included education sessions to learn about the biomechanics and tackling technique, and specific set pieces like the scrum. Rugby union coaches also included collision training against equipment like scrum machines and controlled player-against-player collisions, using tackling shields, and against one another. In contrast, coaches from MMA included prescribed collisions until and into a fatigued state. These exercises included collision sparring rounds, integrated with collision skills like striking and grappling, and muscle endurance exercises, like burpees.

Table 11. Quotations from elite collision coaches for the sub-theme 'Planning collision training.'

	QUOTATION
EXERCISE SELECTION FOR COLLISION TRAINING	*"…there's also teaching sessions… it's maybe 30 or 40 minutes and then I can really talk them through stuff, so they still jump, 100% line-out or scrumming, we do setups maybe, and practicing that pre-engagement facet of the game, that's really giving a lot of times for questions and answers and that's more an interactive session…"*-P1
	"Do a bunch of burpees then after we're fighting again, we have to fight when we're tired, so that's one thing that we've been doing a lot…we're trying to simulate the fight mixed with extra conditioning, so we're trying to get more tired than what we would get in a fight you know. And it's a mixture of grappling and striking every day."-P2
	"We were trying to work on tackle technique in groups of two, so where two guys are making a tackle on one individual, so it's to be clear on what the expectation is each of those individuals and then we packed out an exercise that was in about a 3m x 3m space, or 6m x 3m space, so the contact between the ball carrier and the tackler was 3m and then the spacing between the defenders was 3m."-P3
	"…spend time working on skills and time spent on body positions, then you spend some time working on technique and maybe bag work before you finally go into the contact or the collision training part of the session…"-P4
	"It would be an hour to hour-and-a-half of striking, an hour to hour and-a-half cardio, which is sports specific training. And then another hour to hour- and- a- half of grappling."-P5

4.2.4.2 Collision Training Volume

The following sub-section presents findings related to the collision training volume or amount of collision training prescribed by the collision coaches (Table 12). The prescribed training volume was either higher or lower in proximity to competition or match days throughout the season. The uncertainty surrounding the exact dates of MMA fights resulted in the coaches ensuring that MMA athletes were always 'fight-ready,' thereby prescribing higher collision training volumes than rugby union coaches. The consistent scheduling of weekend rugby union matches resulted in rugby union coaches not risking injury, and in doing so reducing higher collision training volumes.

Collision coaches manipulated training volume to meet the competition demands. Rugby union coaches manipulated the number of training collisions based on a specific number of collision repetitions over a specific duration. Also, the rugby union coaches prescribed more collisions during training than the player would be exposed to during a game. The MMA coaches viewed training volume based on a specific number of rounds where both coaches P2 and P5 mentioned training their fighters to competition championship rounds in MMA.

Table 12. Quotations from elite collision coaches for the sub-theme 'Prescribing collision training based on exercise prescription principles.'

	QUOTATION
VOLUME OF COLLISION DRILLS	*"We do a five-minute block, focusing on the defensive block collision exercise, for eight repetitions, for five to eight phases…a phase defined as an impact."*-P3
	"This position does four collisions every two minutes, this position does seven collisions every two minutes…that doesn't necessarily mean player-on-player collisions, you could do that by using pads or shields…."-P4
	"…as you get closer and closer to the fight, you're not sparring as much…so you might be sparring once a week or three rounds instead of five, unless you're fighting a championship round then you're probably going to do five rounds…"-P2
	"Try to get in at least thirty minutes of sparring. Like heavy, exhausted, where they want to throw up, where they can barely move. I try to get them to championship rounds..."-P5

4.2.4.3 Collision Training Intensity

Most of the coaches prescribed collision training intensity using a verbal numeric measure (Table 13). Coaches manipulated the collision training intensity based on the athlete's experience, with more extraordinary intense collisions for elite athletes and lower intensity for novice athletes. Also, coaches would manipulate collision intensity based on the use of training simulated equipment or live contact: *"Intense contact against bags and then shortened versions with the body on body…"*-P3. The coaches never prescribed live collisions at 100% intensity.

However, live collision intensity reached between 80% to 90% for elite MMA fighters due to their technical experience during collision skills training and ability to avoid injury during collision training. Novice fighters performed collision drills at a lower intensity due to their lack of experience and technical skills.

Table 13. Quotations from elite collision coaches for the sub-theme 'Prescribing collision training based on exercise prescription principles.'

	QUOTATION
INTENSITY	*"…when you're sparring your partner, or you're doing drills, you're never going 100% unless you are elite-level fighters… you've seen these strikes before, there's nothing new to you...but they're still not going 100%, they would be going about 80%, 90% maybe."*-P2
	"…out of ten, ten-out- of-ten being full-contact and then going down the scale you know, so those sessions would probably be anything between a five and an eight out of ten contact."-P3
	"I think it's very difficult to put a number on a collision between players and to desire that at game intensity is probably going to cause the team and each individual player a lot of issues, so maybe that's something that you shouldn't be looking for."-P4
	"...it depends on the coach, I might say go 50%, and 50% in another gym they're trying to knock each other out with body shots. But 50% by me you know going like tap for tap...The fighters don't go a 100% and knock out anybody. Nobody is getting knocked out…"-P5

4.2.4.4 The Duration of Collision Training Sessions

Collision training sessions had a duration of between less than an hour to three hours (Table 14). Coaches from the different sports had substantial differences in the length of their sessions. Collision sessions in rugby union were less than an hour in duration, while the MMA training duration was more significant, ranging from between two to three hours. In rugby union, elite coaches prescribed shorter periods of live collision training once per week ranging from 15 minutes during an international tournament to 30 minutes in elite club scrumming sessions.

In rugby union and MMA, the type of collision task carried a specific timeframe. In rugby union, the coaches allocated more time to collision technique education and collisions using protective equipment, and less time to live collisions. While in MMA collision training sessions, coaches allocated time to striking, grappling, and conditioning.

Table 14. Quotations from elite collision coaches for the sub-theme 'Prescribing collision training based on exercise prescription principles.'

	QUOTATION
DURATION	*"Our training sessions are about two hours, sometimes three, so we'll do two or three hours in the morning, then we'll go home, then we'll come back again and do another two or three hours…"*-P2
	"They won't go longer than an hour, so the idea is not to go one session longer than an hour, so I think you can work anything underneath an hour."-P3
	"…the whole session could easily last an hour, an hour-and-ten-minutes, but within that training session the actual collisions, where it's a person against person, would be maybe you know, ten minutes, 15 minutes maximum."-P4
	"…I had a 30 minute session and 10 minutes of that session I really went hard with mauling and stuff..."-P1
	"…we split it up between two to three hours, depends on how intense we are going that day."-P5

4.2.4.5 The Frequency of Collision Training Sessions

The frequency of weekly collision sessions varied between collision coaches (Table 15). While a maximum training frequency was observed in MMA consisting of up to six days per week, the frequency of rugby union collision training was significantly less - usually one day per week. Furthermore, one MMA and rugby union coach mentioned how the recovery and rest periods of the athletes influenced their frequency of training prescription, specifically after training or games.

Table 15. Quotations from elite collision coaches for the sub-theme 'Prescribing collision training based on exercise prescription principles.'

	QUOTATION
FREQUENCY	*"On a Tuesday is a big scrum day, roughly I push for 30minutes always, but the guys always want to hold me back for 25minutes…that's the physical day."* -P1
	"Right now we're doing them every day, six days a week.…We're training every single day, sometimes two, sometimes three times a day."-P2 *"…after a training session you could get enough rest in about two hours…but unless like after a hard sparring session, maybe we go hard on Saturday, you're probably not going to train after that"* -P2
	"One of our other two training days in the week, the Tuesday or the Thursday, depending on whatever, will be more of a physical day…"-P3 *"Tuesday will be the main collision training session for the week, where most contact training occurs. Wednesday will be an off day. Also, after the game, the players will have an off day; for example, if the game is on Friday, the rest day will be on Saturday, and if the game is on a Saturday, the rest day will be on a Sunday"* -P3
	"…we split it up between two to three hours, depends on how intense we are going that day."-P5

4.2.4.6 Periodisation of Collision Training in Proximity to the Competition

In rugby union, the amount of training (volume) was linked to the duration of collision training. It was prescribed at higher levels during the pre-season compared to the in-season (Figure 4). During the in-season, the collision volumes were adjusted according to the frequency of turnaround time between games, with a longer turnaround time allowing for more time for the players to conduct collision training. A shorter turnaround time resulted in less frequent and lower training volumes: *"…if you have a short turnaround, then the potential for contact is normally lower, people understand that players need to recover…"*-P4.

Figure 4. Quotations from elite collision coaches for the sub-theme 'Prescribing collision training based on exercise prescription principles.'

Similarly, in preparation for a fight, MMA participants had higher training volumes at the beginning of their training camp (Figure 5). In contrast to rugby union, MMA participants maintained a consistently higher volume of collision training throughout the training camp but manipulated collision volume to mitigate injury or when athletes were fatigued and required rest.

"First, boxing is not a seasonal sport, and you can play all year because it is indoor. But now it becomes a season for national champs and the provincial. It is their season because you condition the boxers towards that." -P6. Coaches structurally tapered training volume in combat sports to its lowest during the final one to two weeks prior to competition.

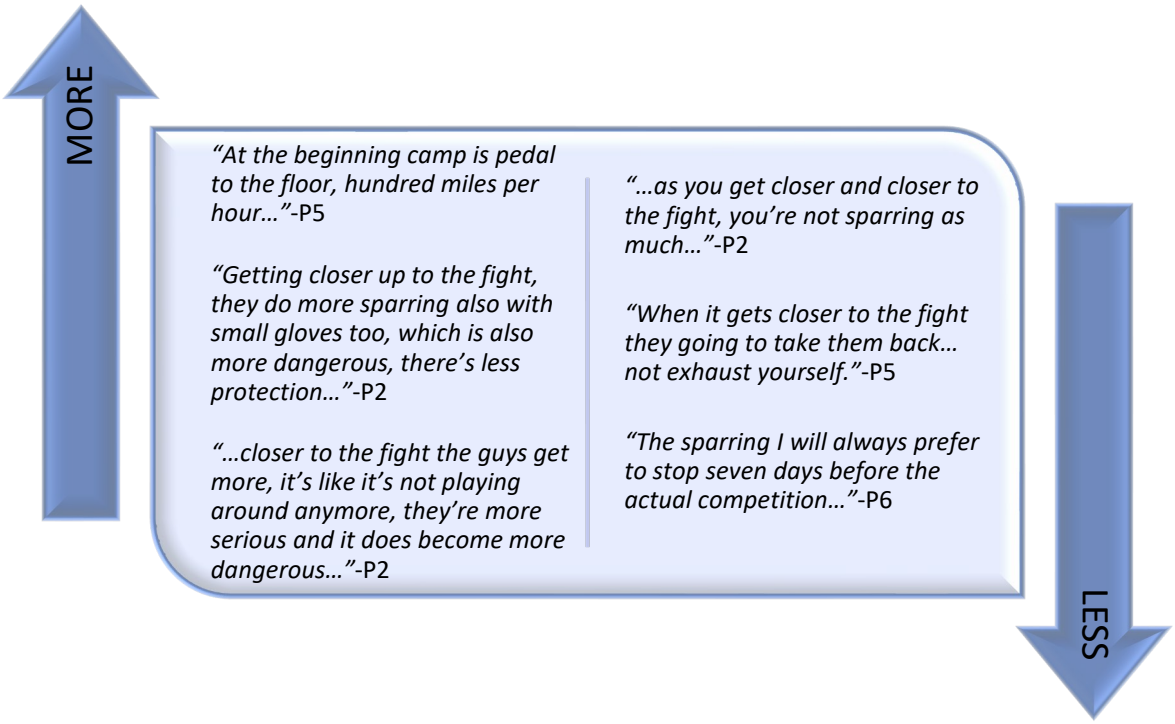

Figure 5. Quotations from elite collision coaches for the sub-theme 'Prescribing collision training based on exercise prescription principles.'

4.3 Adjusting and Measuring Collision Training and Mitigating the Injury Risk

4.3.1 Adjusting Collision Training

4.3.1.1 Collaborations Across Different Sports Disciplines

Coaches discussed their collaborations with other sports disciplines in a sports setting (Figure 6). Collaborations with different sporting disciplines affected how coaches adapted collision training for their athletes. For example, after meeting with different sports disciplines, one coach (P1) stated: *"If the props, maybe their necks are stiff, then we'll take the engage out of it, but we'll fold in…";* similarly*: "…we put them in special groups to say okay this guy can't do contact, this one can do contact this day and that day…"*-P3.

Thus, coaches adjusted their collision training prescription by excluding potentially damaging collision techniques for enhanced athlete safety. Also, collaborations with other sporting disciplines influenced whether athletes could participate in collision training sessions, further indicating a focus on athlete safety.

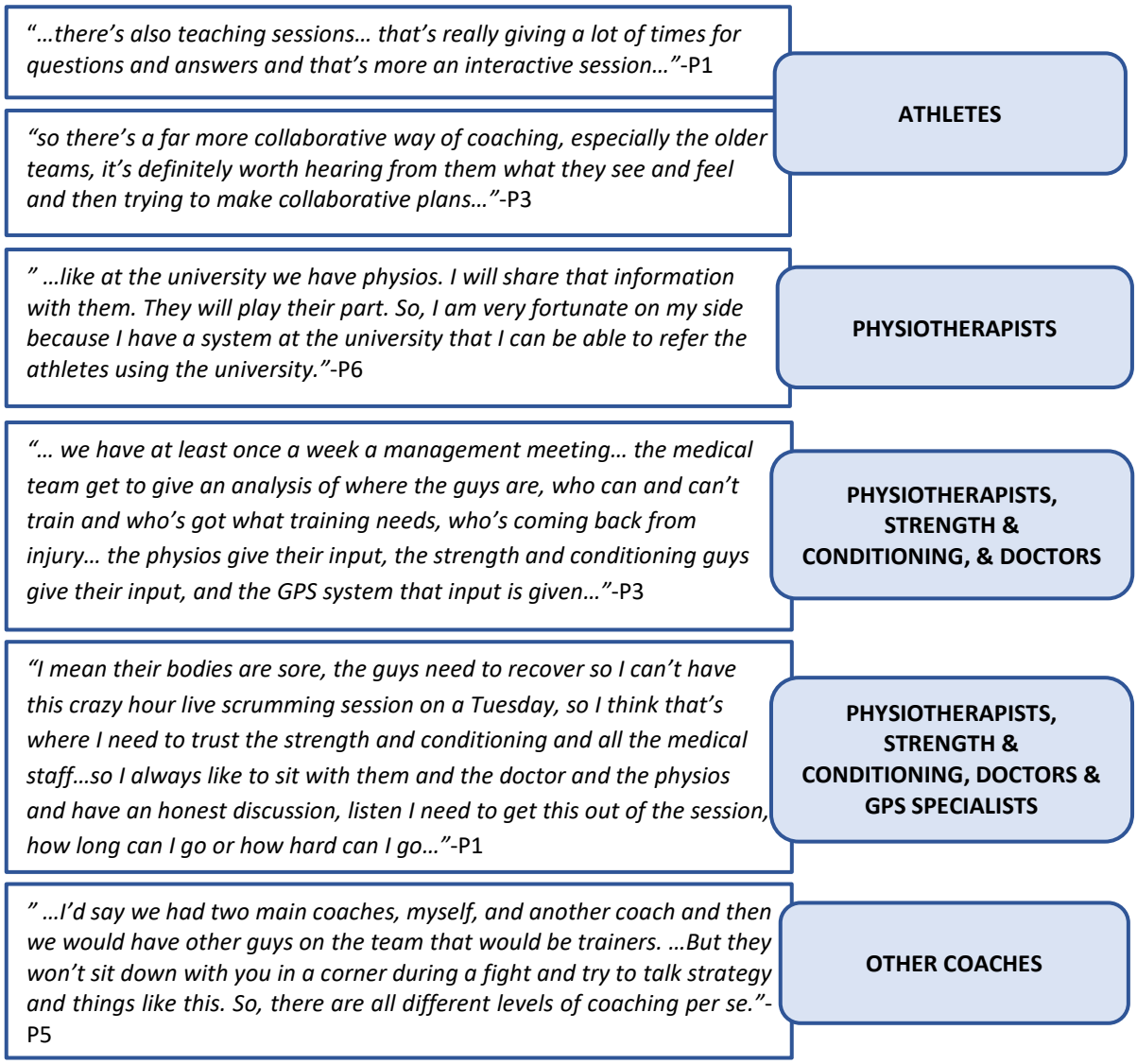

Figure 6. Quotations from elite collision coaches for the sub-theme 'Collaborations across different sporting disciplines.'

4.3.1.2 Protective Equipment and Training Simulated Equipment in Collision Sports

Participants highlighted different types of sports equipment when prescribing collision training. Primarily, equipment related to protective apparel was highlighted: *"…we use the thick shin guards…we use big 16-ounce gloves. We make sure that they have a cup on, athletes have to wear mouth protection and also a helmet."* -P2*;* as well as equipment athletes performed collisions against during training: *"…so tackle bags, contact shields, and high jump mats I think are what we would use the most."* -P3. Participants had differing views on whether using protective equipment provided athletes with safety against injury (Table 16). Most participants viewed protective equipment associated with a head injury as a disadvantage to athlete protection.

Table 16. Quotations from elite collision coaches for the sub-theme 'The advantages and disadvantages of using protective equipment across collision sports.'

ADVANTAGES	DISADVANTAGES
"...we make sure that for the beginners, they're always wearing the big gloves and that also creates a cushion if they throw a move that they're not supposed to or at least there's the big padding…"-P2	*"…I don't have my guys sparring with head gear because you have more blind spots, so you get hit harder…"*-P5
"…it's a lot less stressful to the players…"-P4	*"...the head gear actually absorbs punches more than a human being exposed. So they come up with their research and they tabled. That's why today you find the Olympic boxers they don't wear head gear."*-P6
"The gloves are big in size…but because of the gloves it is heavy. It can't be that punch effective to your opponent."-P6	*"I've seen some fallacies within systems where the tackle suits the players wear, coaches might believe that wearing that provides a large degree of protection…but it's not going to stop an ACL or a head injury…"*-P4
"Tackle suits...in reality it'll protect you against a dead lead or a haematoma..."-P4	*"Few players wear their protective equipment during training that they actually wear during the game."*-P3

4.3.1.3 Training Simulation: Collisions Against Protective Equipment Versus Live Collisions

Coaches included elements of collisions either against training simulated equipment or between players (live collision). In this dissertation, live collision was defined as a player-against-player collision. Coaches across the various sports used simulated equipment to condition athletes for collisions by enhancing athlete confidence, collision repetitions, and collision intensity (Table 17). Participants from rugby union included elements of live collisions but in smaller amounts compared to training simulated equipment: "…*so we prefer to use bags and then if there is contact it is to do exercises or drills that are very controlled and in a shorter space*" -P3. However, P4 highlighted a potential concern with using training simulated equipment to perform collisions: "…*the techniques being used bear little resemblance to what is happening in the game…there has to be more information to coaches around techniques, more education about how you would use these methods correctly…*" The conditioning of athletes to collisions occurred primarily from training simulated equipment in rugby union, and from live collisions in combat sports.

Table 17. Quotations from elite collision coaches for the sub-theme 'Protective equipment.'
This table highlights the collision prescription using equipment and live collisions.

	QUOTATION
COLLISION SIMULATION EQUIPMENT	*"Machine scrumming for me is very limited, the machine doesn't scrum back at you…the scrum machine is like a conditioning tool…it's basically fatigue work and I think there's a mental resilience that players get from scrumming really hard in the off season..."*-P1
	"…the only time you maybe want to go 100% is when you're hitting the bag right, then you can hit the bag as hard as you want…"-P2
	"I think the tackle bags are helpful for building confidence, technique, also for repetition, you can get many repetitions out because the body is not taking strain because of the bags..."-P3
	"...you'd probably want your number of collisions to be higher than they are in a game, not necessarily player-on-player collisions, you could do that by using pads or shields..."-P4
	"We always use protective equipment, if not it's because we're doing body conditioning and the intensity would depend on the pain tolerance of the athlete but never hard to the head."-P5
LIVE CONTACT	*The same with live scrumming, it can also, I mean if you do 20 live scrums in 20 minutes, you're going to struggle with injuries, I can guarantee you that, so it's always this trade-off for me..."*-P1
	"...there's not a lot of bone-on-bone contact, and the bone-on-bone contact is very limited..."-P3
	"...we'll take three guys, and we'll make them fight one guy, but one after another so one guys stays but then one guy goes on that guy and then when the guy gets tired, after a minute, we take him off, we put a new guy on him, a fresh guy on the same guy…"-P2
	"...the live contact you can use to affirm and confirm the contact that was done against the shields."-P3

4.3.2 Measurement in Collision Training

In this dissertation, collision coaches used different methods of measuring collision training. While rugby union coaches highlighted the use of GPS devices to measure the impact of a collision, other methods included the monitoring of athletes' heart rates and fitness levels (Table 18).

Table 18. Quotations from elite collision coaches for the sub-theme 'Measurement of collision training.'

	QUOTATION
QUANTIFYING TRAINING IN COLLISION SPORTS	*"Well I mean we've got a GPS system and the guys wear pods, so GPS guys will know how that stuff works, but I think they record, I guess how long the sessions go and I'm sure the pods have got an ability to measure the actual contact and impact but I can't elaborate on that because I'm not sure of the detail of that, but I'm sure in their system they've got a way of recording how those impacts occur...we use the Catapult S7 Vectors system."*-P3
	"...so it's interesting if you look at GPS data, when you look at GPS data in non-contact or non-collision versus collision training sessions, collision training sessions tend to be a lot slower, so there's obviously a lot going down with the ball being slow, with things like that happening, so it affects the timing of the game."-P4
	"So we do a lot of heart rate monitoring. So you monitor people's heart rate, basically when they wake up in the morning they supposed to check their heart rate and keep a log on if it is too high, that's a rest day, if it is low we know we can push them that day. Then in training they are supposed to wear a heart rate monitor to know exactly where they are and what we looking for."-P5
	"...we set the timer, a stop watch, immediately it will ring, that means it is saying there is one minute to go. Now the boxers they must go all out. It is high intensity. That is one minute. Remember it is sixty seconds, they push, they push, until they get tired. They come back we give them water, rest, and advice."-P6
	"…we split it up between two to three hours, depends on how intense we are going that day."-P5

4.3.3 Mitigating Injury Risk During Collision Training

The presence and feedback from the coaches, from planning to prescribing training collisions, ensured that athletes were safe during collision training. Coaches were present and involved in each collision session and took responsibility of safety by managing the level of intensity and ensuring techniques were safely executed. Coaches controlled their planning by considering the conditioning of athletes and simulating the game. At the same time, collision prescription was controlled by the coaches by manipulating the training volume, intensity, and training periodisation to avoid injury during collision training. In boxing and MMA, the coaches mitigated collision injury risk by observing athletes and how they reacted to particular collision tasks (Table 19).

These coaches would explain the collision drills to athletes: *"What we do is we explain the rules, and I tell the guys what moves they are not allowed to do right, and this prevents injury" -P2*.

Table 19. Quotations from elite collision coaches for the sub-theme 'Mitigating injury risk during collision training.'

	QUOTATION
MITIGATING COLLISION TRAINING	*Yeah, so it is a risk, you are taking a risk every time you know, something could happen to you, maybe, but that's why the coaches are there, the coaches are watching…"*-P2
	"So, what I am looking for is how much damage they are taking but how they react when they get hit."-P5
	"So also that's where, whenever there is a sparring there is a supervision with the head coach, or the coach. So actually, we avoid injury, because we are able to analyse the punch when it causes damage to the athlete."-P6

4.3.4 How Collision Training Has Changed Over Time

This topic highlights how collision training has changed over time and will aid in fulfilling the dissertation's objective of identifying elite coaches' current collision training prescription by comparing past and present collision training prescriptions. The development of collision training was a common finding linked with rule changes for half of the included coaches. Rule changes were specific to adjusting collision techniques in rugby union and MMA as well as the headgear change in boxing (Table 20). Other topics that changed over time were more advanced protective equipment, technology, and specific collision exercise prescription protocols with a greater focus on player safety. The development of technology, specifically GPS devices, aided the monitoring of collision training (P3 and P4). The more frequent use of online learning portals in rugby union allowed athletes to learn, prepare for matches, and ask questions (P3).

Table 20. Quotations based on the subtheme 'How collision training has changed over time.'

FACTORS	QUOTATION
RULE CHANGES	*"I think the change of the rules made a lot of the things better; …it was crouch, touch, pause, engage, now it's crouch, bind, boom."*-P1
	"Yeah because your rules change slightly over time. That's the problem with MMA, it is evolving so much… So if it changes, it does change how you would coach…"-P5
PROTECTIVE EQUIPMENT	*"Back in the day they would have thin, thin shin guards, now we use the thick shin guards right, and back in the day you used to have small gloves, now we use big 16 ounce gloves."*-P2
TECHNOLOGY	*"When I was playing, in the early 2000's, we didn't have GPS monitors or anything like that…"*-P3
	"I mean there was no such thing as a GPS then, very little was involved in the sport in terms of technology, towards the end of my time there I started using [indistinct] for measuring barbel velocity, we had speed gates and the ability to monitor [indistinct] movement and that was our lot."-P4
COLLISION PRESCRIPTION	*"I mean in my time we scrummed for two hours, it's crazy…", "it made you mentally tough but it completely stuffed up your back…The coach made us maul 50m mauls for an hour, at least we could maul at the end of the day but we also had injuries…"*-P1
	"…a lot of people have gotten hurt over the years and you know, we're a lot more safer now, like in sparring now, we don't use…there's certain moves that we've taken away from beginners right, so there's certain moves we're only allowed to use when we're more advanced"-P2

4.4 Results Summary

When planning collision training, the coaches all determined that it was necessary to include training collisions to simulate the game environment as a main priority, and thereafter to condition the players' bodies for competition. The coaches also considered the athlete's skill level and focused on prescribing appropriate collision tasks based on the athlete's experience. Although the coaches prescribed collision training with protective equipment for both elite and novice athletes, their reasoning differed based on the athlete's skill level. Elite athletes primarily used protective equipment to enhance the intensity of their collisions.

In contrast, the coaches placed a greater significance on building confidence in the collision technique for novice athletes than on increasing collision intensity. To a greater extent, the coaches prescribed collisions against training simulated equipment such as tackling shields, instead of prescribing live collisions between athletes. However, coaches prescribed more live collisions between athletes in combat sports than rugby union, but while wearing protective equipment such as gloves and shin guards.

The coaches prescribed collision training based on the proximity to the competition. Coaches determined the number of fighting rounds in boxing and MMA and the number of tackles in rugby union training from the number of rounds or tackles in the game. Similarly, the intensity of collision training sessions was higher than, or comparable to, game intensity but with added protective equipment. The duration of collision training was longer in combat sports than in rugby union, with combat sports ranging from between two to three hours, whereas rugby union was generally for less than an hour. The frequency was also greater in combat sports than in rugby union. Collision training occurred as high as six days per week in MMA, whereas rugby union coaches allocated only one day per week, usually a Tuesday, for collision training.

Collision training prescription has changed over time. The coaches interviewed for the present study prescribed fewer live collisions in rugby union and used protective equipment during collision training across all the included sports. The coaches adjusted collision training based on sporting rule changes and after team meetings with other sports disciplines. While coaches in rugby union measured collisions using current GPS technology, the coaches from combat sports directly observed athletes' collisions to monitor the risk of injury.

CHAPTER FIVE: DISCUSSION

The present study explored the collision training perspectives of six elite coaches from collision sports locally across South Africa and internationally from Canada, the United Kingdom, and Trinidad and Tobago. The discussion section will follow the progression of the three main themes identified in the results section: the development and progression of coaching expertise, planning collision training, and adjusting, monitoring, and measuring collision training. Also, in this chapter, we included the study limitations and recommendations for future research.

5.1 The Development and Progression of Coaching Expertise

The present findings noted commonalities in collision prescription. All the coaches learned how to prescribe collision training from sources such as past athletic experience, former club involvement as a mentor, and from other coaches. Similarly, in a descriptive online survey study aiming to explore coaches' perspectives of their actual and preferred methods of acquiring new coaching knowledge, Stoszkowski and Collins (2016) reported that most coaches (92.5%) preferred informal sources of learning such as peer discussion (41.5%). Their sample included 320 coaches (31 females – most from the USA, and 289 males – mainly from the United Kingdom; Stoszkowski & Collins, 2016).

In our study, MMA coaches (n=2) demonstrated continuous self-athletic development and believed informal coaching to be the best way to improve their coaching ability. Another MMA coach highlighted the lack of an MMA coaching qualification and highlighted learning from athlete experience and informal learning routes, noting the scarcity of formalised MMA training programmes. Similarly, another study interviewed four MMA coaches and found that they developed their coaching practice via experiential and peer learning (Kirk, 2022).

While the present research may have highlighted informal coaching learning as a primary source of learning, Stodter and Cushion (2019), in a pragmatic quasi-experimental design, reported that a formal coaching programme had improved learning outcomes in youth coaches. Their study included eight youth coaches, observing two filmed coaching sessions per coach using an adapted version of the Coach Analysis Intervention System to analyse behaviours. The authors concluded that completing a formal education course influenced tactics, player engagement, and behaviours geared toward youth athletes (Stodter & Cushion, 2019). They also found that when coaches completed a formal education course, it influenced their knowledge around tactics and engagement with individual players, and reflected in an altered proportion of technical to tactically related questions and a trend towards increased behaviours directed at individuals (Stodter & Cushion, 2019).

Similarly, national rugby injury prevention programmes such as BokSmart from South Africa and RugbySmart from New Zealand include formal online coaching from World Rugby to train coaches prior to the commencement of coaching in rugby union (New Zealand Rugby, 2018; South African Rugby, 2023). In the present study, the results suggested that while one South African rugby union coach (n=1) completed formal rugby-related training, he did not find it directly beneficial in teaching collision prescription skills. This coach highlighted that he primarily based teaching collision training on past athlete experience as an international country and club player. Similarly, previous research has highlighted that sports education training programmes concerning planning training must be specific to the coach's profile and needs to follow a socio-constructivist approach, honing in on an experiential and reflective approach (Roy, Roy, Chevrier, & Cardinal, 2018).

5.2 Planning Collision Training

5.2.1 The Necessity of Collision Training

In this study, we obtained views from rugby union, MMA, and boxing coaches' on why they thought collision training was necessary. The present findings demonstrated that elite coaches (n=5) greatly emphasised simulating the game or the competition environment when asked about the necessity of collision training. Further, when coaches (n=2) explained the necessity of collision training, they included the conditioning of the players' bodies to meet the demands of the competition matches which were most frequently played over the weekend.

When asked whether the collision training environment was predictable or unpredictable, coaches (n=2) considered that while their sessions were unpredictable, there was still an element of coaching constraint by using instructions, protective equipment, and limiting specific collision techniques. In contrast to coaches physically preparing athletes for training, previous research considered 10 elite Australian taekwondo athletes in a systematic review and highlighted that fighting in training does not adequately simulate the competition environment due to lower levels of anxiety, arousal, decreased mental challenge, and different movement behaviour (Maloney, Renshaw, Headrick, Martin, & Farrow, 2018). However, in the present study, coaches from boxing and MMA (n=2) highlighted diversifying training with other clubs to ensure that they challenged fighters appropriately. Collision training encompassed simulating the game environment for competition preparation and developing the athlete's collision skills.

5.2.2 Developing Collision Skills in Novice Athletes

In the present study, youth players and novices were classified under the same category due to the similarities in collision training prescriptions related to collision skill development. In considering collision skill development, coaches (n=4) considered the experience level and safety of the athlete.

Similarly, Davids et al. (2013) concluded that successful skill-learning design was based on the expertise level of the athlete, constraints that can be manipulated during learning, and the goals to be understood. When developing skills in novice athletes, one MMA coach noted the removal of specific advanced collision techniques during training to avoid injury. Also, one rugby union coach stated that using tackling bags builds tackle confidence in youth rugby union players. Further, researchers have previously recommended that coaches developing collision skills for experienced athletes should consider repeating sessions at a lighter skill load before progressing to more challenging sessions (Hendricks et al., 2018).

From the present findings it was noted that the rugby union coaches (n=2) allocated most of the Tuesday collision training session for developing or maintaining collision techniques in youth and under-19 level rugby union players, specifically in South Africa. These techniques included tackle and scrum. According to Hendricks et al. (2018), rugby union coaches should consider different coaching styles such as prescriptive, descriptive, and guided discovery, when prescribing collision training for collision skill development. The first coaching style concerns instructing the player to perform the required actions and movements, and the next style informs the player that an error has been made and an improvement can be made. The last coaching style allows the players to learn solutions to movement challenges by exploring and discovering themselves (Hendricks et al., 2018).

Therefore, when developing collision skills leading up to a competition, coaches should be concerned with the athlete and reflective of their coaching style. A prescriptive coaching style was linked to highly structured, low representative tasks and facilitated high practice performance but low skill retention and transfer. In contrast, a guided-discovery coaching style was used in a practice match and facilitated a common practice performance but high skill retention and transfer to the game.

5.2.3 Periodisation of Rugby Union Collision Training in Proximity to the Competition

Coaches planned their training sessions with the match day in mind. According to coaches from rugby union, the highest volume of collision training was prescribed in the preseason. During the in-season, coaches all had specific reasons for including collision training. In this study, rugby union coaches (n=2) highlighted collision training based on performance during the previous match. Similarly, Hendricks et al. (2018) highlighted that during the in-season, coaches have several training goals and collision training may be included based on match fixtures and outcomes of the previous match. Further, the authors highlighted that tackle and technical collision skills should be a requirement during the in-season (Hendricks et al., 2018).

During the in-season, coaches from rugby union (n=3) carried out their collision training prescription similar to the guidelines set out by World Rugby. For example, one elite rugby union (forward set-piece) coach conducted *30 minutes of high-intensity* set-piece, including scrumming and mauling, weekly on a Tuesday. According to the World Rugby guidelines, set pieces such as the scrum are to be conducted for 30 minutes once per week at match intensity (World Rugby, 2020c). An expert consensus from World Rugby has documented collision prescription parameters. Rugby union coaches prescribed a higher volume of collisions per player during training than the players were exposed to during matches, but the prescribed intensity limited the collision intensity. For frequency, contact training should be conducted *twice* weekly, on *Tuesdays* and *Thursdays*, to allow for recovery before and after weekend matches (World Rugby, 2020c). In the present study, all of the rugby union coaches (n=3) prescribed small doses of specific collision training in collaboration with athletes and other sports specialists for elite club rugby. The progression of collision training should ideally be individualistic; however, if this is not possible due to a team setting, progression should be based on coaching observation, assessment, and the athletes' training session response (Hendricks et al., 2018).

5.2.4 Periodisation of MMA and Boxing Collision Training in Proximity to the Competition

While rugby union matches were scheduled well in advance, the dates for MMA fights were often unpredictable, as highlighted by the MMA coaches (n=2). The MMA match unpredictability required coaches to adapt their training to a shorter or longer turnaround time to maintain a constant match-ready state for the athlete. Therefore, MMA coaches must be able to manipulate exercise prescription variables, including collisions, over both shorter and extended preparation periods. There is a scarcity of research concerning the prescription and progression of collision volume in MMA and boxing. Across the included combat sports, there was a gradual broad-based progression towards increasing the volume based on collisions in a specified time. Therefore, volume was linked to the duration, precisely the number of required competition rounds. The intensity of collisions was typically the highest during training camps and typically increased towards the course of match preparation. In an eight-week observational study of MMA (n=14) participants, researchers highlighted an intensity distribution of 47% low, 33% moderate, and 20% high intensity (Kirk et al., 2021).

In the present study, one boxing coach highlighted using a seven-day tapering phase before the competition wherein the athletes did not do sparring. Another researcher highlighted using a ten-day tapering phase wherein they continued with technical training but reduced the training intensity (Halperin et al., 2016). Other researchers have demonstrated no effect on the one-week tapering phase to decrease athlete fatigue (Kirk, 2022). The MMA coaches in the present study (n=2) highlighted decreasing sparring loads and not exhausting fighters the closer to the fight. Therefore, there is inconclusive evidence to highlight the exact duration and training components of the tapering phase in boxing and MMA.

5.3 Adjusting, Monitoring, and Measuring Collision Training

5.3.1 Adjusting Collision Training Prescription Through Collaboration Across Sports Discipline

Most of the coaches in this study (n=3) discussed their collision sessions with physiotherapists and collaborated with athletes, doctors, and strength and conditioning coaches. The coach's prescription varied throughout the season depending on the athlete's health/injuries and point in the season. Similarly, one rugby union coach highlighted that meeting with other sports specialists helped categorise players into different levels of contact (collision): 'contact, semi-contact, or non-contact.' Further, research on non-collision sports injury prevention and performance optimisation has highlighted that injury prevention in elite sports following training for maximal performance relies on teamwork, shared responsibility, and open communication (Bolling et al., 2020). While it is apparent that coaches communicate with and listen to athletes in the sports setting, broader decision-making concerning whether athletes may or may not conduct collision training when injured remains with the coach and the management team.

Research suggests that a learning process through experiences influences how athletes manage injury prevention and that this learning process should be facilitated by coaches and physiotherapists (Bolling et al., 2020). This facilitation by the coach or physiotherapist can relate to their profession-specific knowledge regarding injury prevention, performance optimisation, and experience as a professional athlete. In this study, coaches collaborated with other sports specialists and directly adjusted collision training. During collision training, coaches from MMA (n=2) and boxing (n=1) highlighted a hands-on coaching approach by directly observing collisions between athletes and altering their collision prescription during the session. Further, commonalities across MMA (n=2) and rugby union (n=1) coaches included prescribing collision training using a verbal numeric scale, either as a number from zero to 10 or a percentage value from zero to 100%.

Therefore, coaches possess the inherent ability to identify specific cues from the athlete and their environment based on their experience and to make a judgment call to increase or decrease intra-session collision training intensity.

5.3.2 Adjusting Collision Training by Using Protective Equipment

All of the coaches in this study (n=6) highlighted using protective equipment during collision training. The rugby union coaches (n=3) highlighted that the players performed collision tasks against equipment such as tackle bags or tackle shields. However, they highlighted that players typically avoid wearing protective equipment in training as opposed to competition, such as headgear and shoulder pads. Researchers explain this phenomenon by highlighting the non-compulsory rules for wearing protective equipment in competition, allowing athletes to choose whether to wear the equipment during competition and training. Although protective equipment in certain sports is mandatory during competition, athletes were not guaranteed to wear it during training.

Simulating the game environment was limited when prescribing live collisions between players. All coaches (n=6) prescribed the highest intensity collisions against training simulated equipment such as tackle shields, tackle bags, and punch bags, thereby reducing the possibilities of collision-related injuries between athletes. Therefore, coaches from different collision sports backgrounds appeared to share a similar focus on player well-being, performing fewer live collisions and more collisions while using protective equipment. Apart from online practical videos regarding collision techniques using training simulated equipment such as tackle bags, it was surprising to note the necessity for peer-reviewed research on conducting collision techniques against training simulated equipment, such as tackle bags, shields, and scrum machines. A former international rugby union coach highlighted progressing collision volume by altering collision drills from controlled contact to full contact using training-simulated techniques, protective equipment, and specific collision techniques such as tackling bags and shields.

5.3.3 Monitoring and Measuring Collision Training Using the Rate of Perceived Exertion, Global Positioning System, and Heart Rate Monitoring

When asked how collision training was monitored, it was surprising to note the coaches did not use the RPE to monitor collision training. Currently, researchers in rugby union have focused on using cost-efficient subjective measures such as the RPE to monitor the athlete's perceived training experiences (Hendricks et al., 2019). In a descriptive survey of 20 professional rugby union strength and conditioning coaches, using session-RPE to monitor training load was highlighted. In contrast, 14 coaches reported collecting RPE for all of the training aspects players were exposed to (Comyns & Hannon, 2018). Most of these coaches (n=17) collected the RPE verbally. A scoping review by Shushan et al. (2022) highlighted that the RPE in team sports should be collected as a discreet activity with smaller groups, or RPE collection procedures like mobile devices and human recourses. Therefore, while there is research to support the notion of including the RPE as a monitoring tool in team sports, there are numerous considerations regarding its practical implementation (Comyns & Hannon, 2018; Shushan et al., 2022).

Additionally, the rugby union coaches (n=2) stated that their teams used GPS to monitor the athletes' collisions during training. The rugby union teams had persons specialising in GPS technology who provided feedback during weekly management meetings. Similarly, researchers have highlighted the advantage of GPS in providing practical information related to variables during passing (drill) or small-sided game exercises (Shushan et al., 2022). In individual sports such as MMA, there is inconclusive evidence on whether GPS measurements are useful (Kirk et al., 2020). Researchers have reported that professional MMA coaches monitor external training load using torso-mounted accelerometery (Kirk, 2022).

One MMA coach used heart rate monitoring to monitor the intensity of the collision training. Similarly, researchers in combat sports (i.e., taekwondo and karate) have stated that heart rate monitoring is one of the most prevalent monitoring tools for cardiovascular endurance and training intensity (Slimani, Znazen, Sellami, & Davis, 2018). However, its ability to display adverse effects on the autonomic nervous system in team sports is uncertain (Shushan et al., 2022). Therefore, the heart rate assessment of combat athletes should be combined with tools such as the RPE (Slimani et al., 2018).

5.4 Dissertation Strengths, Limitations, and Recommendations for Future Research

This dissertation was the first to explore elite coaches' perspectives regarding collision training prescription. We included international participants from developed and developing countries and various collision sports backgrounds. There were several limitations in the dissertation. Qualitative studies using the grounded theory approach tend to have more than six participants; however, some studies have included seven participants (Bluff, 2005). A larger sample size could have allowed for more significant information collection, comparison, and generalisation of collision training prescription. Therefore, the results of this study provided limited practical applicability to collision sports. Nevertheless, while our dissertation included grounded theory techniques, its primary purpose was not theory development as it was a qualitative descriptive dissertation.

The dissertation included English-speaking participants, and future research should incorporate coaches who may not speak English to improve collision prescription understanding. Furthermore, future studies in collision training may benefit from including athletes' perspectives on collision training. While we included one team collision sport (rugby union), and two individual collision sports (MMA and boxing), future research could contain a more significant variation of team and individual collision sports to be more representative of the collision sports population.

In our dissertation and other studies coaches primarily obtained collision prescription skill from informal and experiential sources of learning. Therefore, coaching collision skills development should include practical components that incorporate online or face- to-face discussions of collision training prescription between coaches. Future qualitative research should build on the perceptions of elite coaches in simulating the competition environment during training as in our dissertation, coaches (n=6) all saw it necessary to simulate the competition environment during training. Further, we did not consider the differences in collision prescription between male and female participants. Therefore, future qualitative studies should include questions directed at the differences in collision prescription between female and male athletes. Future research should build on the perceptions of elite coaches in simulating the competition environment during training and focus on collision training prescription such as the collision volume, intensity, duration, and collision activity.

Additionally, we recommend future qualitative studies include subjective instructions given during collision training using perceived athlete exertion scales, such as zero-to-10 or zero-to-100%. Regarding the application of the RPE by coaches after training, future qualitative interview studies with collision coaches should include questions regarding why and how coaches use the RPE to monitor collision training loads. Further, we did not consider the differences in collision prescription between male and female participants. Therefore, future qualitative studies should include questions directed at the differences in collision prescription between female and male athletes.

CHAPTER SIX: CONCLUSION

Collisions are the leading cause of injury during collision sports competitions (Thomas & Zamanpour, 2018; Williams et al., 2013) but the number of successful collisions during competition are also a predictor of competition success (Gabbett et al., 2010). Collisions during training are an essential skill that can be taught, refined, and enhanced by coaches and is, therefore, a crucial aspect of preparing athletes for the game. There has been a call for collision training programmes to detail the frequency of collisions, intensity, collision activity, duration, conditions, and the number of sessions (Hendricks et al., 2017). This dissertation aimed to explore the perspectives and practices of elite coaches regarding collision training prescription. We included six coaches from individual and team collision sports and addressed the specific objectives of this dissertation as outlined below:

(a) explore the current collision training perspectives of elite collision coaches for collision training planning, necessity, and risks:

In this dissertation, all the coaches' perspectives of collision training prescription stemmed from prior learning as a former athlete and via informal coaching learning. All the coaches prescribed collision training with the competition day in mind and used protective equipment and training equipment to avoid the damaging effects of training collisions. While coaches in established collision sports such as rugby union appeared to be up to date with the current World Rugby consensus guidelines for collision training, the coaches from MMA and boxing require collision prescription guidelines. Coaches included collision training as a form of competition simulation and athlete conditioning for collision skills development. Although coaches could mitigate collision training injuries using hands-on coaching supervision, they frequently discussed training with other sports specialists and athletes.

(b) describe the established exercise prescription parameters such as frequency, intensity, duration, activity, and volume, regarding collision training prescription:

There was a greater collision training frequency, volume, and training duration in MMA and boxing than in rugby union. Coaches prescribed a higher intensity of collision training, more advanced collision techniques for advanced MMA athletes, and lower collision intensity and novice collision techniques for beginner MMA athletes. In MMA, competition preparation involved collision prescription under conditions of fatigue but with coaching supervision.

In rugby union, there were more extended rest periods between collision training sessions than in MMA and boxing. Nevertheless, in MMA and boxing, coaches considered collision prescription with a pre-competition tapering period in mind, where athletes were prescribed a lower frequency, intensity, volume, and less dangerous collision technique activity. In rugby union, coaches varied their collision training prescription based on the purpose of their training session. For example, while one collision training session may have simulated the competitive environment in terms of intensity and volume, another session focussed on skill development or correcting collision tactics from the previous match. In rugby union the intensity and volume of collisions in training were higher than in the game. The coaches prescribed a frequency of once to twice per week, and training sessions were split into forward and backward collision training sessions. The forwards typically performed higher volumes of collision training focusing on scrumming and tackling, whereas the backs primarily focused on tackling.

The highest volume of collisions was against training equipment, including tackling bags for novice athletes. For elite athletes, coaches still used training equipment and live collisions. In the preseason, the highest volume and duration of collisions were prescribed in rugby union. In comparison, the in-season and end-of-season saw a decreased collision training volume and was specific according to the purpose of the training session.

(c) describe differences in collision prescription across the participants:

All of the rugby union coaches held a university-level qualification (n=3); however, coaches from combat sports did not (n=3). All of the coaches were present during collision training sessions and supervised their athletes. They also played a vital role in teaching athletes the required collision skills. Most of the coaches (n=3) prescribed collision training intensity using a verbal numeric scale, either zero to 10 or zero to 100%. All the coaches (n=6) refrained from using subjective tools such as the RPE to monitor the collision training load. For half of the coaches (n=3), collision training was influenced by rule changes in the sport.

This dissertation was the first to explore the collision training perspectives of elite coaches from different collision sports settings. Collision training has changed over time, with coaches in rugby union now prescribing low-duration, high-intensity collisions with protective equipment. In contrast, when the coaches in the present study were athletes themselves, their own coaches spent more time on training collisions, placing them at greater risk of training injury. The change in prescribing a lower collision training duration highlights a shift towards athlete well-being, improving injury prevention and performance enhancement. Also, prescribing specific collision doses concerning rest days demonstrates an understanding of the physiological collision consequences of collisions such as IIMD and player adaptation. This dissertation contributed to stage three of the TRIPP framework by modestly adding to literature on collision sports injury prevention and training prescription by elite coaches. Future research should continue stage three of the TRIPP framework and consider studying collision training prescription in professional collision sports settings to develop a collision training preventative measure. Researchers should monitor collision training prescription over a sports season together with injury and performance data to better understand the injury risk and performance.

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APPENDICES

Appendix A: COnsolidated Criteria for REporting Qualitative Studies (COREQ)

Developed from: Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care*. 2007. Volume 19, Number 6: pp. 349 – 357.

No.	Item	Description	Page Number(s)
Domain 1: Research team and reflexivity			
Personal characteristics			
1.	Interviewer/facilitator	Which author/s conducted the interview or focus group?	51
2.	Credentials	What were the researcher's credentials? *E.g. PhD, MD*	ii & 51
3.	Occupation	What was their occupation at the time of the study?	ii & 51
4.	Gender	Was the researcher male or female?	ii
5.	Experience and training	What experience or training did the researcher have?	51
Relationship with participants			
6.	Relationship established	Was a relationship established prior to study commencement?	49 & 50
7.	Participant knowledge of the interviewer	What did the participants know about the researcher? *E.g. Personal goals, reasons for doing the research*	51
8.	Interviewer characteristics	What characteristics were reported about the interviewer/facilitator? *E.g. Bias, assumptions, reasons and interests in the research topic*	57 & 58
Domain 2: Study design			
Theoretical framework			
9.	Methodological orientation and theory	What methodological orientation was stated to underpin the study? *E.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis*	48
Participant selection			
10.	Sampling	How were participants selected? *E.g. purposive, convenience, consecutive, snowball*	49
11.	Method of approach	How were participants approached? *E.g. face-to-face, telephone, mail, email*	49 & 50
12.	Sample size	How many participants were in the study?	50
13.	Non-participation	How many people refused to participate or dropped out? What were the reasons for this?	60
Setting			

14.	Setting of data collection	Where was the data collected? *E.g. home, clinic, workplace*	53
15.	Presence of non-participants	Was anyone else present besides the participants and researchers?	51
16.	Description of sample	What are the important characteristics of the sample? E.g. demographic data, date	60 & 61
Data collection			
17.	Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?	51,52,120-125
18.	Repeat interviews	Were repeat interviews carried out? If yes, how many?	53
19.	Audio/visual recording	Did the research use audio or visual recording to collect the data?	53
20.	Field notes	Were field notes made during and/or after the interview or focus group?	57
21.	Duration	What was the duration of the interviews or focus group?	51
22.	Data saturation	Was data saturation discussed?	50
23.	Transcripts returned	Were transcripts returned to participants for comment and/or correction?	53
Domain 3: analysis and findings			
Data analysis			
24.	Number of data coders	How many data coders coded the data?	53
25.	Description of the coding tree	Did authors provide a description of the coding tree?	N/A
26.	Derivation of themes	Were themes identified in advance or derived from the data?	53 & 54
27.	Software	What software, if applicable, was used to manage the data?	53
28.	Participant checking	Did participants provide feedback on findings?	53
Reporting			
29.	Quotations presented	Were participant quotations presented to illustrate the themes / findings? Was each quotation identified? *E.g. Participant number*	59 to 83
30.	Data and findings consistent	Was there consistency between the data presented and the findings?	59 to 83
31.	Clarity of major themes	Were major themes clearly presented in the findings?	59 to 83
32.	Clarity of minor themes	Is there a description of diverse cases or discussion of minor themes?	59 to 83

Appendix B: Informed Consent Form

Collision training prescription in collision sports by elite coaches: a qualitative study

Invitation to participate in an online interview on collision training prescription

We are conducting a study to explore how elite coaches prescribe collision training to generate a substantive theory to guide collision training prescription. This will form part of a master's dissertation through the University of Cape Town by Faeez Williams under the supervision of Dr. Jason Tee and A/Prof Theresa Burgess. We would like to invite you to participate in this 'pre-interview' screening survey.

Background:
Impact-induced muscle damage is caused by compression of skeletal muscle by an external stimulus (i.e tackle or punch or grappling) against the impact site. Various sports contain high-contact collisions among athletes, playing objects, and playing surfaces. These sports are described as collision, contact, or combat sports. The "collisions" athletes are exposed to during training may hinder sports performance by reducing function and recovery. However, exposure to collisions in training is beneficial, leading to improved contact skills and increased resilience to impact-induced muscle damage and/or collision injury. Limited research is available for frameworks describing the safe prescription of collision training. The purpose of this study is to determine how elite coaches in collision sports balance the need for collision training against its damaging consequences.

To take part in this study, you must:
a. Speak English fluently
b. Have coached within a collision sport at an elite level within the last 5 years (this may be at a national, international, professional league including elite university leagues).

What will the study involve?
If you decide to participate, you will be asked to take part in an online Zoom interview. The date and time will be secured and discussed via your preferred method of communication. The interview will involve open-ended questions (such as "How would you prescribe…?") and closed-ended questions (such as " How frequently does training occur?..."). The interview will last for approximately 40-50 minutes.

How will your privacy be protected?
All information will be stored on a password-protected computer. The researchers will not report on any personal, identifying information in the study (i.e., Your name, place of employment/organization will be completely anonymous). Pseudonyms (such as participant X) will be used as a means of participant identification to protect your confidentiality.

Potential risks associated with the research:
The privacy and confidentiality of the interview data may be limited, as quotes may be reported in this study, and papers arising from this study. Moreover, this study may elicit the sharing of competitive industry information related to collision training.

Potential benefits associated with the research:
There are no direct, individual benefits to taking part in this study. However, each participant may benefit from the interview by engaging in a process of 'Sensemaking' around their contact prescription practices. The advancement of tacit or procedural coaching knowledge to declarative coaching knowledge through 'Sensemaking' activities is a recognized form of professional development for coaches.

Return of results:
Upon completion of the study, if you would like to receive the results, they will be sent directly to you. This may take approximately 3-6 months

Questions
If you have any questions or concerns about the study do not hesitate to contact one of the individuals listed below. All inquiries will remain confidential.

Yours sincerely
Faeez Williams
BSc Physiotherapy (UCT)
Email: faeezwilliams12@gmail.com
Cell: +27 84 207 8943 or Whatsapp +27 81 546 3378

Research Supervisors:
Dr. Jason Tee
Email: jasonctee@gmail.com
Cell: +27 62 335 9308
A/Prof Theresa Burgess
Email: theresa.burgess@uct.ac.za
Tel: +27 21 406 6171

If you have ethical concerns or questions about your rights and welfare as a research participant, the University of Cape Town Faculty of Health Sciences Human Research Ethics Committee can be contacted as listed below.
Email: hrecenquiries@uct.ac.za
Tel: +27 21 406 6338

Please confirm if you have read and understood the information and provide your informed consent to participate. *

- ○ Yes
- ○ No

Please indicate if the following statement applies to you: "You have prescribed collision training (i.e tackling or hitting or grappling) at an elite level within a collision sport at any time over the last five years". This this may include at a national, international, or professional league including elite university or college leagues. The sport must include either rugby, American football, boxing, mixed-martial arts, or wrestling. *

Please provide a brief description if 'other' was selected.

- ○ Yes
- ○ No
- ○ Other...

Which country do you currently live in? (i.e South Africa) *

Short answer text

What is your timezone? (i.e South African Standard Time UTC +2:00) *

Short answer text

What date and time would be most suitable for you to be interviewed? *

Please use 24-Hour Clock Time (i.e 16:00)

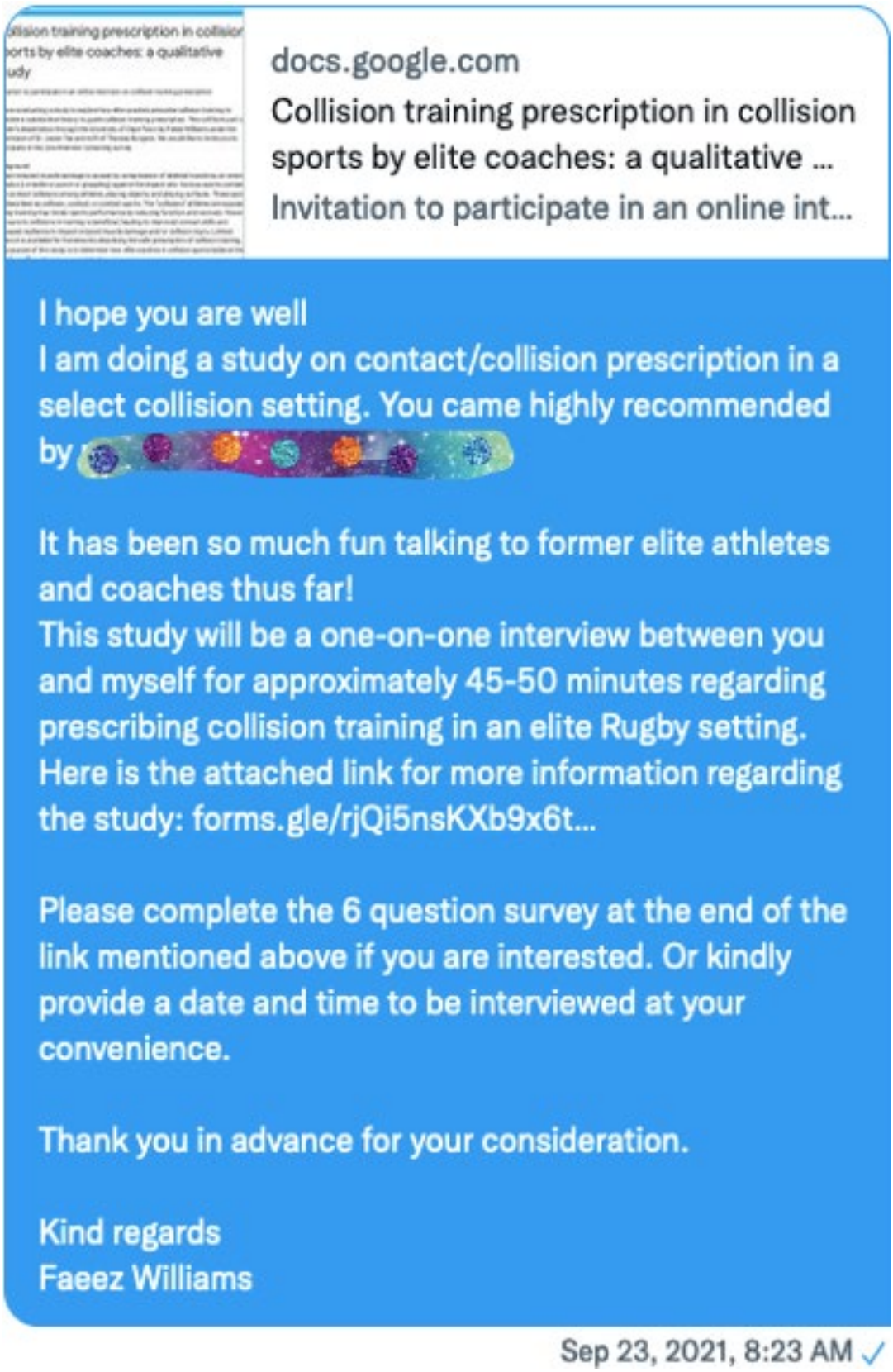
Month, day, year

Time

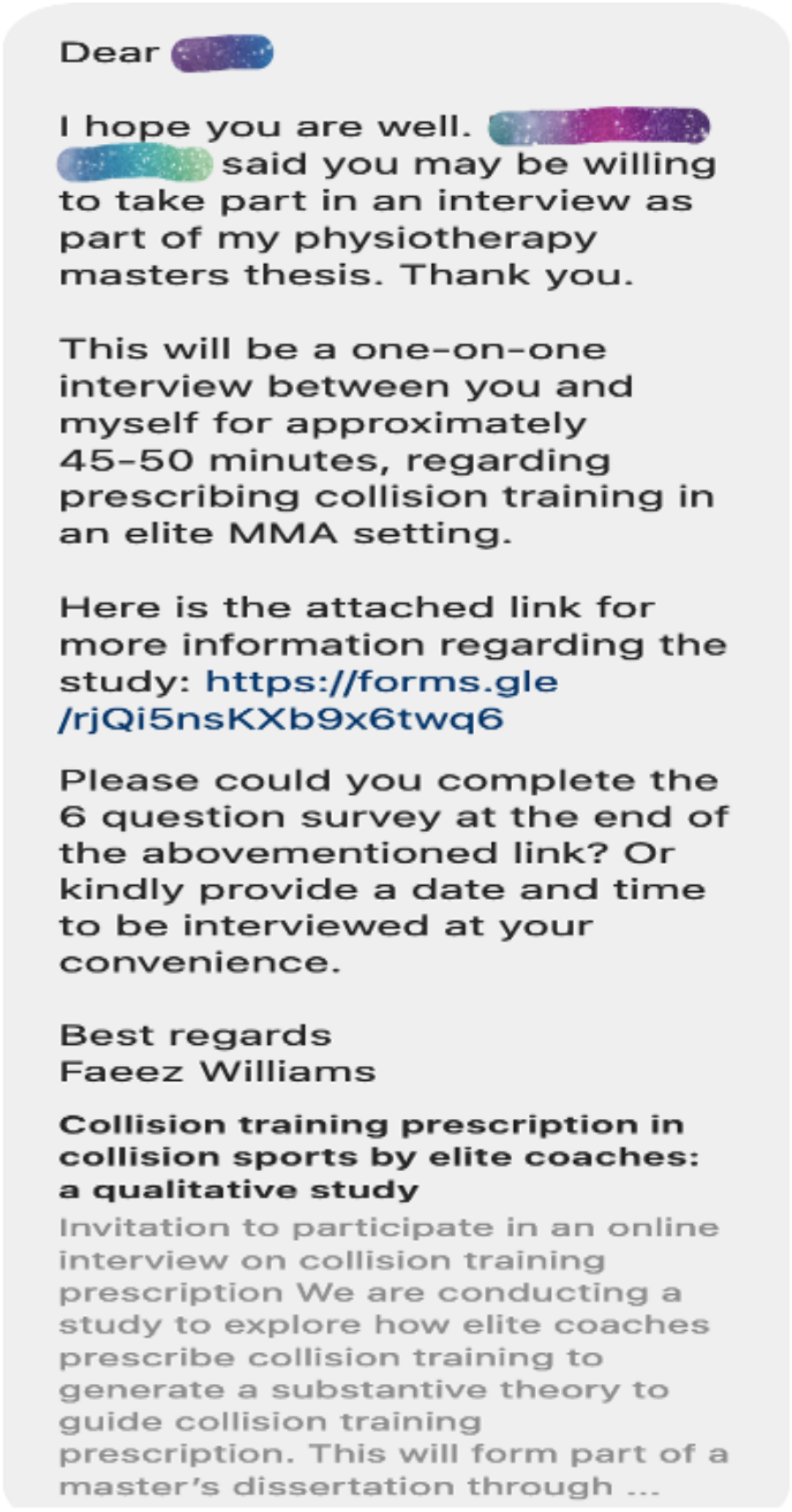
If you choose to participate, what is your name and contact details? (i.e your preferred method of communication: email or cell or social media or other)

Long answer text

Appendix C: Social Media Recruitment via Twitter



Appendix D: Social Media Recruitment via Instagram



Appendix E: Sports Organisation Recruitment via Email

Postgraduate Research Study- Interview with a Boxing and Wrestling Coach Add label

F

Faeez Williams

to [redacted]

Dec 9 View details

Dear [redacted]

I am a postgraduate physiotherapy student at the University of Cape Town. I am conducting an interview study exploring the collision-training prescription among ten elite collision coaches in various countries in different collision sports (boxing and wrestling).

The interview will occur via a one-on-one online Zoom interview between myself and the participant. I would appreciate the opportunity to invite any coach who has coached at an international or national level to share their coaching journey, and talk about training.

Please see the link below containing the informed consent form explaining the study in more detail: https://forms.gle/rjQi5nsKXb9x6twq6

Appendix F: Pilot Interview Guide

Gender: **Age:** **Context:**

Role: **Years of experience:**

Introduction		
Thank you, (participants name), for agreeing to be interviewed! (enthusiastic) I'm (Researcher names), a Physiotherapy Masters Student researcher at UCT. Purpose: This interview aims to understand better how you prescribe collision training during practice. - Emphasise confidentiality- Your name and other personal information, such as coaching club, will not be used in any subsequent correspondence. However, the researcher may report the information you provide in the study. - This interview is about gaining your perspective of the collision or contact training– (there are no wrong answers). - Participants are not being judged for their contribution. Understanding how MDT's currently work may be a catalyst for improving practice in the future.		
Warm-up questions		
1. Could you tell me a bit about you and your coaching background? 2. How did you become the coach at your club? 3. How many years of experience do you have in such a role? 4. What qualifications do you have? 5. Can you describe your current position at the club? 6. What are your responsibilities for coaching contact or collision in the sport?		
Main questions		
Main Question	Prompt	Probes
Can you tell me about your process of prescribing collision training?	1. How do you prescribe collision training? 2. Why do you prescribe collision training? 3. Who is involved in the process? How does it come together? 4. Has the process changed? Has it ever been done differently?	1. How often per week do you prescribe collision training? Why? 2. How intense are your collision training sessions? Why? 3. How long does a collision session last? Why?

	5. How do you weigh-up the need for collision training against the damage consequences?	4. What was it based on/informed by? Why this way? 5. Can you give examples? Why? In what way?
Can you tell me about your role in collision prescription?	1. What are your responsibilities? 2. What parts of the process are you involved with? 3. Who do you have to work with, and in what way? 4. How often do you interact with other MDT members?	1. Can you give examples of the types of things you do in a normal week that would fall under collision training? 2. How does that work?
What processes would you put in place if you got free reign for collision prescription at the club?	1. Why these? 2. Would they replace anything? 3. What would they improve?	
Cool down		
"That covers the things I wanted to talk to you about. Is there anything you would like to add?"		
Closure		
- I will send you a summary for your check the accuracy of what was discussed. - Ask if they would recommend any coach to interview for this study. - Thank them very much for their help and remind them about confidentiality.		

Appendix G: Amended Interview Guide

<table>
<tr><td colspan="3">Introduction</td></tr>
<tr><td colspan="3">Thank you for agreeing to be interviewed! (enthusiastic)
I'm Faeez Williams, a Physiotherapy Masters Student researcher at UCT

Purpose: This interview aims to understand better how you prescribe collision training during practice.

- Emphasise confidentiality- Your name and other personal information, such as coaching club, will not be used in any subsequent correspondence. However, we may report the information you provide in the study.

- This interview is about gaining your perspective of the collision or contact training– (there are no wrong answers).

- Participants are not being judged for their contribution. Understanding how MDT's currently work may be a catalyst for improving practice in the future.</td></tr>
<tr><td colspan="3">Warm-up questions</td></tr>
<tr><td colspan="3">1. Could you tell me a bit about you and your coaching background?
2. How did you become the coach (mention participant's coaching place)?
3. How many years of experience do you have in such a role?
4. What qualifications do you have?
5. Can you describe your current position at the club?
6. What are your responsibilities for coaching contact or Collision in the sport?</td></tr>
<tr><td colspan="3">Main questions</td></tr>
<tr><td>Main Question</td><td>Prompt</td><td>Probes</td></tr>
<tr><td>1. Contact/Collision training has inherent risks. Why is it necessary to prescribe contact/collision training during practice?</td><td>• How did you reach this understanding?
• What would happen if you didn't include contact/collisions in your training?</td><td>• Have coaches always prescribed collisions this way, or is this a new development? What has changed?</td></tr>
<tr><td>2. How do you weigh-up the need for collision</td><td>• Is there an optimal amount of collision to prescribe?</td><td>• Do you think about mitigating the</td></tr>
</table>

training against the risk of injury/muscular damage caused?	• How do you know what this is?	risk of collision training? • How do you mitigate the risks?
3. Can you tell me about your process for prescribing of collision training?	• How do you plan a collision training session? • What are your key considerations when planning a training session?	• How intense are your collision training sessions? Why? • What was it based on/informed by? Why this way? • Can you give examples? Why? In what way?
4. How often do you schedule collision training sessions? (frequency)	• What would the optimal frequency of collision training sessions be? • What other factors affect scheduling of these sessions? • Do you consider how long it takes to recover from these training sessions?	• Why do you train collision at this frequency? Why not more or less often? • Does the frequency of training change at different times of the season?
5. How do you control the intensity of collision training sessions? (intensity)	• Are all collision sessions at all out intensity or do you vary intensity? • What factors affect the collision intensity that you prescribe?	• Do you use an intensity prescription scale, e.g., 6 out of 10? • Are some exercises inherently more intense than others? Do you

		choose different activities to moderate intensity? • How does the choice of equipment affect the intensity of sessions?
6. How much collision exposure does an athlete receive during a typical session (Volume)	•	• How long is a typical collision training session? • How many collisions do you think players are exposed to in that time?
7. How does your collision training prescription change over the course of a season? (periodisation)	• Do you use different exercises/volumes/intensities at the beginning of the season versus the end?	• How did you learn to set up your season in this way?
8. Do you think of collision/combat/ contact abilities as a skill or a physical capability?	• What is the best way to train that skill/capability?	• Do you generally prescribe collision training under controlled our unpredictable training conditions?
Cool down		
"That covers the things I wanted to talk to you about. Is there anything you would like to add?"		

Closure
- I will send you a summary to check the accuracy of what we discussed in the interview. - Could you recommend any coach to interview for this study? - Thank them very much for their help and remind them about confidentiality.

Appendix H: Human Research Ethics Committee Approval Letter

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room G50- Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: hrec-submissions@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

23 July 2021

HREC REF: 450/2021

A/Prof T Burgess
Division of Physiotherapy
Health & Rehab Sciences-OMB
Email: Theresa.burgess@uct.ac.za
Student: WLLmog018@myuct.ac.za

Dear A/Prof Burgess

PROJECT TITLE: COLLISION TRAINING PRESCRIPTION IN COLLISION SPORTS BY ELITE COACHES: A QUALITATIVE STUDY-MSC CANDIDATE-MR FAEEZ WILLIAMS

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19, dated 17 March 2020 & 06 July 2020.

Approval is granted for one year until the 30 July 2022.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Mr Faeez Williams will also be involved in this study.

Please quote the HREC REF 450/2021 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

Signed by candidate

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE

HREC/REF450/2021sa

UNIVERSITY OF CAPE TOWN

FACULTY OF HEALTH SCIENCES
Human Research Ethics Committee

FHS016: Annual Progress Report / Renewal

HREC office use only (FWA00001637; IRB00001938)			
This serves as notification of annual approval, including any documentation described below.			
☑ Approved	Annual progress report	Approved until/next renewal date	28/02/2024
☐ Not approved	See attached comments		
Signature Chairperson of the HREC/ Designee	Signed by candidate	Date Signed	8/2/2023

HUMAN RESEARCH ETHICS COMMITTEE
08 FEB 2023
HEALTH SCIENCES FACULTY
UNIVERSITY OF CAPE TOWN

Note: Please email this form and supporting documents (if applicable) in a combined pdf-file to hrec-enquiries@uct.ac.za.
Please clarify your plan for research-related activities during COVID-19 lockdown.
Please use the latest form found on our website:
http://www.health.uct.ac.za/fhs/research/humanethics/forms

Comments to PI from the HREC
Thank you for the declaration document

Principal Investigator to complete the following:

1. Protocol information

Date (when submitting this form)	07/02/2023		
HREC REF Number	450/2021	Current Ethics Approval was granted until	30 July 2022
Protocol title	Collision Training Prescription in Collision Sports by Elite Coaches: A Qualitative Study		
Protocol number (if applicable)	n/a		
Are there any sub-studies linked to this study?	☐ Yes	☒ No	
If yes, could you please provide the HREC Reference number for all sub-studies? **Note:** A separate FHS016 must be submitted for each sub-study.	n/a		
Principal Investigator	A/Prof Theresa Burgess		
Department / Office Internal Mail Address	F45 OMB GSH theresa.burgess@uct.ac.za		

1.1 Does this protocol receive US Federal funding?	☐ Yes	☒ No

(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)