PRACTICAL APPLICATIONS OF STRENGTH AND CONDITIONING PRACTICES IN ELITE MALE FOOTBALL

Michael Beere

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Graduate **R**esearch **O**ffice

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ASSOCIATED PUBLICATIONS

Findings from this portfolio were published as two separate papers in a peer-reviewed journal

Project 1a)

Beere, M, Jeffreys, I and Lewis, N. Strength and Conditioning provision and practices in elite male football. *Professional Strength and Conditioning Journal* 27-33, 2020.

Project 1b)

Beere, M and Jeffreys, I. Physical testing and monitoring practices in elite male football. *Professional Strength and Conditioning Journal* 27-33, 2021.

ABBREVIATIONS

CMJ	Countermovement jump
Dom	Dominant limb
EBP	Evidence based practice
EBS	Exercise based strategy
GPS	Global positioning system
HB-RFD	High baseline RFD
HBF	High baseline force
HMLD	High metabolic load distance
HSI	Hamstring strain injury
HSR	High speed running
IPC	Isometric posterior chain
IPEP	Injury prevention exercise programme
LB-RFD	Low baseline RFD
LBF	Low baseline force
MCT	Muscle capacity test
MF	Mean force
ND	Non dominant limb
NF	Neuromuscular function
NHE	Nordic hamstring exercise
PF	Peak force
PS	Pre-season
RFD	Rate of Force Development
RM	Repetition maximum
S&C	Strength and conditioning
SL	Single leg
TD	Total distance
TL	Training load

ABSTRACT

This overview draws together the findings from three projects, each exploring the implementation of strength and conditioning (S&C) practices in professional football, and how these practices are applied in the real-world setting. The overview combines the findings to explore the relationships between the different projects and aims to build a more comprehensive understanding of the three concepts in this particular context.

This portfolio consists of three projects. Project one comprises of an in-depth questionnaire of 51 high level S&C, sports science and medical practitioners' currently working in male football. The questionnaire focused on examining staff structure, qualifications, the S&C practices currently implemented by practitioners', with reference to programming, use of technology, the skills required for successful coaching, challenges faced and opinions on the future of strength and conditioning research. The outcome of the survey allowed the creation of two separate published research papers (Beere et al., 2020; Beere & Jeffreys 2021).

Project two examined injury occurrence in professional football players over two consecutive pre-season phases at one football club. The unique aspect of this project was that on-field training load was the same in both pre-seasons, with the implementation of a structured S&C programme the only intervention in the second. In addition, the same 20 players were included. The findings revealed that the inclusion of an S&C programme during the 2nd pre-season phase reduced soft tissue incidence, average severity, and total severity in elite football players.

Project three explored the content and delivery of an S&C programme across a full football season. Isometric strength testing was used to monitor the changes in maximal isometric force and rate of force development capabilities in response to the concurrent training programme and match play. Findings highlighted that force-specific changes can occur at different phases of the season, in response to differing density of match and S&C practice. Additionally, results highlighted the requirement to view changes on the individual level as well as the overall group change. Importantly, the results also showed for the first time that strength can be improved in professional footballers within the context of a full competitive season.

Together, the results of the three projects were utilised to develop a greater understanding of the process applied by practitioners, and provided two practical case study examples highlighting the use of S&C in elite male football. Results were made available to the wider S&C community for the first time (project one) and provided many previously unreported findings (project one and three). The novel findings reported in project three showed for the first time that strength and rate of force development can be improved across a competitive season. This not only challenges previous research, but also gives practitioners' evidence to chase strength and RFD gains in-season as well as pre-season.

There are many aspects to a S&C practitioners' role in a professional football club. The aim of this portfolio was to bring together a number of these aspects to provide a detailed body of evidence for myself and others to utilise in the context of their practice. Thus, the overview provides an empirical basis for a new way of understanding applied S&C research in senior professional male football and suggests a practical way forward for developing practices in this domain.

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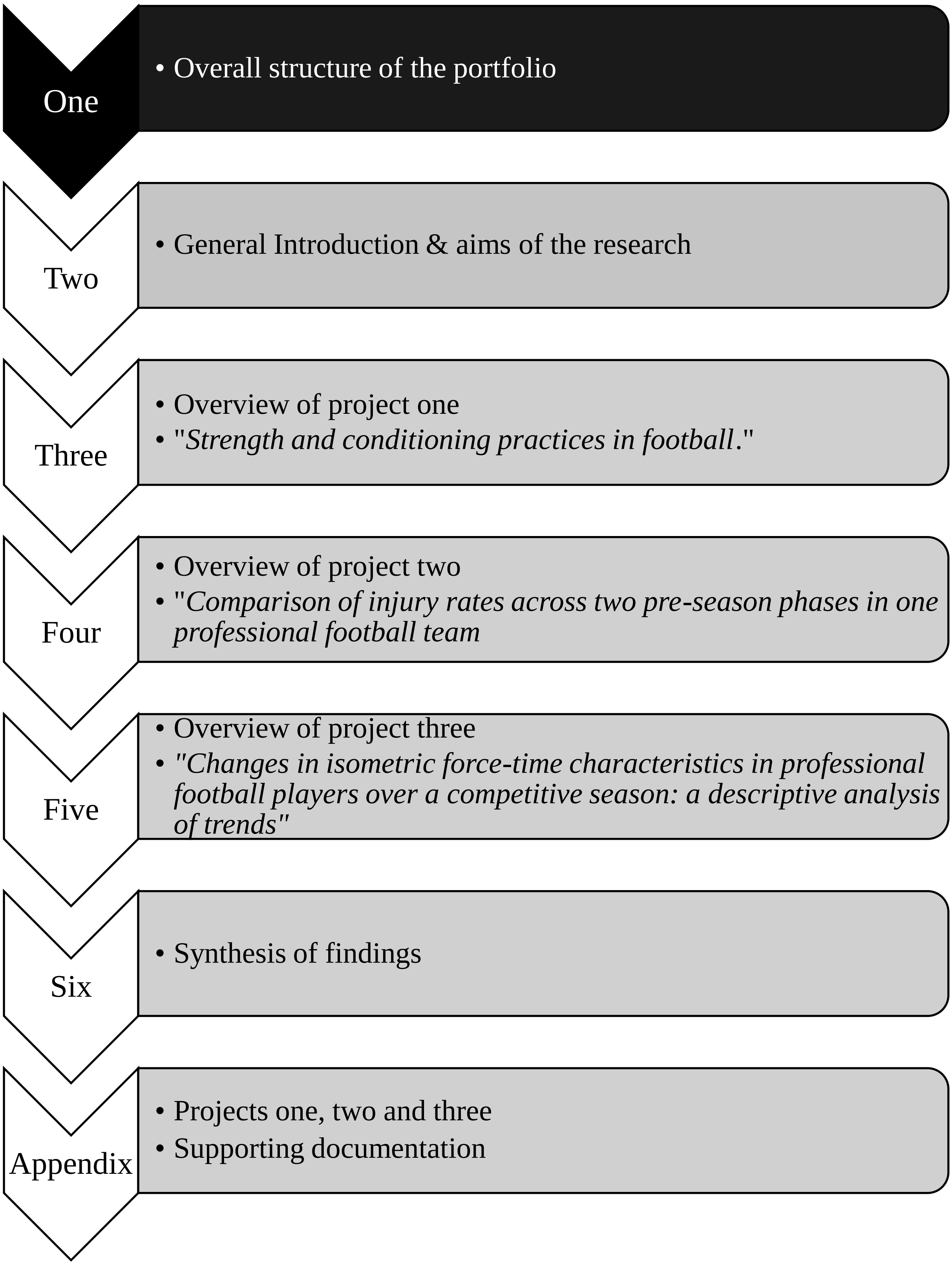

CHAPTER 1

STRUCTURE OF THE PORTFOLIO

This portfolio comprises 6 main chapters and contains three projects that include three original, empirical studies:

1) a survey of current strength and conditioning practices in elite male football;

2) a practical application of strength and conditioning practices in relation to injury prevention in a single football team across two pre-season phases; and

3) a commentary of the practical application of strength and conditioning practices and isometric force output across a full competitive football season in a single team.

One
- Overall structure of the portfolio

Two
- General Introduction & aims of the research

Three
- Overview of project one
- "*Strength and conditioning practices in football*."

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- Overview of project two
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- Synthesis of findings

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CHAPTER 2

GENERAL INTRODUCTION

2.1 Setting the Scene for the Research

The world of professional sport can often require different solutions to many problems. In terms of strength and conditioning specifically, many factors may need to be considered when applying a programme. For example, how do we ensure all players are developing and improving physical qualities associated with athletic performance during a football season? How can we best reduce the risk and severity of injury in players? What's the best periodisation strategy to utilise during a congested in-season fixture schedule? Are all forms of force application capacity relevant to our practice? Do athletes respond differently to the same training stimulus? Are we able to predict and limit the risk of injury in our players? What are the most valuable and reliable measures to determine successful programming? Do "best practices" exist at all levels? In fact, when it comes to delivering successful programmes to top level athletes, the training conundrum is usually more complex than meets the eye (Buchheit, 2017; Carling et al., 2018). As a consequence, in professional football environments, some procedures come from practitioner experience and their subjective frameworks of "*what works in the real world*" rather than research evidence. As such, and since every context tends to be unique, there are many practices deemed appropriate to the individual environment, that may not yet be validated by research guidelines but that practitioners' may feel suitable to their squad of players (Van Hooren & Bosch et al., 2017). For example, periodisation strategies may be learnt via formal education, scientific journals or books, but this information may not form the practitioners' everyday practice, instead a strategy can be shaped, modified, formatted and specialised to the situation and environmental requirements of the sport. Therefore, some of the research-based knowledge becomes the practitioners' practical-applied knowledge.

The majority of research contributing to the S&C practitioners' knowledge is focused on examining the scientific components of programme design, assessment and technique (Baechle & Earle, 2009; Beattie et al., 2014; Maloney et al., 2014). However, researchers have provided theoretical and empirical evidence that there are psychological, social and environmental factors that influence performance beyond what may be highlighted in scientific research that occur in professional practice (e.g., day to day practice in the field) (Gearity, 2010; Tod et al., 2009). Additionally, basic knowledge from scientific research does not always fit directly into practice, but rather results in the S&C practitioner crafting that knowledge to the environment. In fact, Tod et al. (2009) suggested that most aspects of practitioners' practical knowledge were developed through field-based experience, real-life practices, and interactions with other professionals. Consequently, to further understand the relationship between research driven science and the application of practice, researchers should explore how S&C practitioners apply scientific knowledge and personal professional knowledge into practice.

In order to establish a better understanding of effective practices, research into your own practice may need to be conducted. Promoting and publicising research within the elite sporting domain should be seen as one way of enhancing practitioner understanding of what may or may not be achieved. McCall et al., (2015) has suggested that researchers and practitioners at the elite level should work together to ensure that future research is directly applicable to the real-world. With this in mind, these real-world examples of research could potentially help practitioners’ deliver a higher quality programme of performance enhancement and injury prevention. A review by Drust (2019), suggests that evaluations of the current strategies within football, would not only help current practice, but also have the potential to identify future developments of S&C and sport science provision in football. Drust (2019) continues to state that “*little focus is therefore given to the translation of research findings into either the development of the “real-world” strategies or approaches to the implementation of applied football science protocols into professional organisations*” (pp. 4). Understanding the fluid relationship between research, or scientific-based knowledge, and professional, practical knowledge should be seen as essential to assist the development of practitioners’, the service we provide our athletes and to drive the industry forward. Therefore, the narrative seen in throughout the projects submitted in this PhD is that of “practically applied, real-world strategies” that may help, not only bridge the gap between academia and professional football, but also encourage new ways of thinking when implementing protocols for injury prevention and strength training during the competitive season in elite male football.

In an attempt to address the overall aims of the portfolio, this section highlights the personal reasons for undertaking this PhD. Firstly, I wanted to understand my own practice in greater depth. Professional sport is a challenging environment. Enhancing athlete development and reducing risk of injury is a challenging prospect especially when confronted with the high training and match demands placed on the players throughout a competitive season. Finding the time available to include strategies that may help develop athleticism and reduce the risk of injury is a barrier that many practitioners are faced with in senior football (project 1a). The risk of injury is high, with an association between player availability and team success (Hägglund et al., 2013) and the potential financial implications of injuries can be a great burden for many football clubs, with the average cost of hamstring injury can be €500,000 (Ekstrand et al., 2013). Many practitioners are judged on injury rates and keeping players available for match selection is of paramount importance. As a practitioner in professional football of 10 years I have always been strong in my view on the benefits of traditional strength training for professional footballers. This standpoint has often been challenged and questioned by players and coaches who have their own opinions of "*what works for footballers".* My programming philosophy has softened slightly, whereby I now appreciate that there are "more ways to skin a cat", but my training values still remain: increasing an athletes strength capacity, increasing their tolerance to overall training load, or "robustness", and that improving their ability to produce force in game specific situations will help develop athleticism to compete and reduce their risk of injury.

Finally, in addition to this PhD challenging my own professional practice and for me to gain a greater understanding of what may be required to help the team and players on an individual basis reduce the risk of injury and increase physical capacities to aid performance, I also wanted to use the results to help the performance staff across the club develop a greater strength and conditioning service to enhance player development and provide a small part in a successful football club. I have been fortunate enough and privileged to be employed by Cardiff City FC for 10 years. I feel it is my duty as Senior Strength and Conditioning coach to help enrich the strength and conditioning programme throughout the club.

2.2 Developments in Strength and Conditioning practices in football: A reflection on the evolution of my own practice

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In this section I will explore the developments of S&C practices that I have seen during my 10 years working in professional football. These references will be purely anecdotal from my own experiences. As such, I feel this narrative will help explain why I chose to complete my PhD, and what I wish to achieve with the findings. In addition, a number of my personal observations and experiences are supported by those of other practitioners' that are reported in paper one. Finally, I will reflect on my journey as a researcher and practitioner as a result of my PhD studies and highlight how I have used reflective practices methods throughout this time.

My first exposure to the world of professional football was when I was 16 years old. I was fortunate enough to complete a week's work experience at Manchester United FC, where, at the time, my Uncle was one of the Academy coaches. Fast-forward a number of years, and after completing my Undergraduate degree in Sport and Exercise sciences at University of Birmingham, I found myself at a crossroads in where I wanted my career path to lead me. Post University, I applied for a number of internships at professional football and rugby clubs. Eventually, I was fortunate to be given the opportunity to be an intern at Swansea City FC. The season I spent at Swansea was a fantastic experience that allowed me to put into practice some of the theory I had learnt during my degree, but more importantly begin to see behind the curtain of sport science practices in professional sport. Practices I felt were adequate for training athletes were challenged in a way to help me understand their application. Additionally, I learnt a lot about the environment of professional sport that I would never have been exposed to in University. At the end of the season, I was afforded the opportunity to work for Cardiff City FC, initially with the U23 development squad, but with regular assistance to first team sessions.

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One of the ideologies I initially had when I started working in football, and since my time at Swansea, was that I wanted to change the direction and attitude of S&C practices in football. However, my idea of a S&C revolution, whereby I would change the football culture and approach to S&C practices, hit a number of bumps in the road. Subsequently, overtime, I realised this would be a process of evolution, not revolution. The challenges and barriers to implementation of my S&C revolution were initially hard for me to understand and comprehend. For someone who loves the process of S&C practices, and felt I understood the benefits for professional footballers, it was hard to understand that S&C (in the form of traditional strength / resistance training) was not always viewed in a positive light by players or staff, and subsequently wasn't one of the main focusses of the training programme. I had a number of strong conversations with players and staff who had objecting views on traditional strength training. I was referred to the "rugby guy who wanted to ruin football" by one player – despite my experiences in football outweighing those in rugby.

I found the common response to the implementation of S&C were "this doesn't look like a movement we do on the grass"; "how is this football functional?"; "that will get them too big"; "he's got too much muscle"; "is this going to slow me down?". While I couldn't understand this, I was advised by my senior college at the time that "have you ever tried to convince a Christian that God doesn't exist" or "an atheist that God does exist?". His rationale was that sometimes not everyone believes in something (in this case in traditional strength training) to the same extend as me, but that we should appreciate this, have conversations, try to understand each other's side, and try to reach an agreement where both parties are happy with the outcome. For example, for those who were adamant they didn't want to "heavy load with a barbell", could we find an alternative such as the use of pneumatic air pressure loading, as with the Keiser functional trainers, or isometric or eccentric strength

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work, or improve on movement efficiency, or improve core strength and control. How do we show them this work will have a positive benefit to them? Is it phrasing S&C as "injury prevention" for those who have had chronic or a long line of injuries? Or as "performance enhancing" for those who may not have an injury history, but who need to enhance their physical capabilities into order to improve their chances of playing and performing consistently. This idea of working and communicating with the players in a manner where we can achieve a common goal is something I hadn't fully appreciated up until then. Critically, when reflecting on this time, it was a big turning point in how I approached players and staff and played a big part in my practice going forward.

Reflective practice has become an integral part of coaching practices in recent years. Reflective practice is a purposeful and complex approach by which practitioners can explore and question their decisions and experiences within the context of their own practice (Knowles, et al., 2014). Furthermore, Knowles et al., (2014) suggests that "it is the capacity of coaches to practice, reflect and then learn from their experiences that is central to developing coaching effectiveness" (pp. 1712). Reflective practice has recently been advocated as an approach for S&C practitioners to question, learn from, and understand their own experiences to adapt and/or change their subsequent behaviours and decision-making processes.

As a practitioner in professional sport, I have access to data of all sorts to evaluate athletes, to track these athletes' improvements and to support their decision making process, and as such has become a key consideration in supporting my practice. However, while all training sessions are planned and recorded in detail, reflection on my own practice is far less formal. Often this is just thinking to myself, talking to another practitioner, or making a quick note about how to structure a forthcoming session. Within this, the reflection is mainly on myself and how I felt the session was delivered and / or how I felt athletes perceived it. I will consider what may have worked, what may not have worked, what the reasons for that are, and what needs to be put in place next time. This may be considered a form of reflection-on-action, as purposed by Knowles et al., (2014). In addition, it is also common for me to reflect and assess my coaching during the actual session. It has been proposed that for coaches, reflection-in-action may occur regularly as a matter of thinking-on-your feet (Schön., 1983). An example of this may be adjusting an individual players gym volume (number of sets and reps performed) as a result of notable fatigue or due to technical failure of an exercise.

As mentioned, the increase in available data on an athlete is ever increasing. As highlighted in project 3, assessment of individual players response to the training across a season was monitored. The data I obtained from the isometric force test allowed me to reflect on the players adaptation to the training stimuli. As a result of this data, I was able to continually reflect, adapt and innovate for each athlete across the season to try and ensure an overall positive adaptation.

Overall, I often engage with more self-critical reflection, focusing more on the negative aspects of a session or incident rather than the successes. For example, I would spend more time worrying about the content of a training program if a player got injured, than I would if we had won a game or players had improved in their physical performance tests. While this practice may help me, I believe I may develop as a coach if I focussed my time on more positive refection. What I have found as a result of my PhD studies, is that the practices I put in place have the potential for reducing injury rate and improving strength in my athletes. In addition, I may wish to consider what I do well by creating a high compliance rate to our S&C programme that in turn helped injury rate and performance improvements. I could may

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be have more confidence in praising myself as a practitioner, a coach, and a person as to why players have consistently adhered to my programme.

During my time at Cardiff, I have worked under 8 (and counting) permanent managers; 7 head of fitness / performance (a role that I previously occupied on a number of occasions), numerous head of medical, and alongside countless players. This has taught me that the while I need to have strong mindset to stick to my personal philosophy, the evolution, reflection and adaptation of my philosophy and programming is extremely important in the professional sporting environment. Many factors influenced this evolution and adaption. Manager philosophy, training structure and schedule, head of performance philosophy and mindset, and most likely the biggest factor is individual player: their understanding, desire, history and expectations of S&C training. I have found that the ability to adapt to these frequent changes is key in promoting longevity and successful programming. I can honestly say that over this time there has been a change in mentality, appreciation and understanding from staff and players with regards to S&C practices. This concurs with other practitioners' working in elite football highlighted in project 1a; whereby 94% of coaches believe there has been a positive change in attitude from players towards S&C practices during their time working in football. This is not to say that every player now loves lower limb strength training and it forms an equally important part of the training schedule for everyone, but there is a far greater appreciation of the role, and the benefits of resistance training from the players. While I would love to claim all the credit for this change withing Cardiff City, I feel the football world has evolved whereby academy aged players are exposed to S&C practices from a much earlier age, which therefore allows it to be engrained in their mindset as they hopefully progress to first team football. As more players complete this journey, the application of S&C becomes more of the norm with senior football. Furthermore, the increasing physical

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demands of elite football now require players to be “fitter, faster and stronger” than maybe previously expected, with players and coaches understanding that such physical capacities may have a positive effect on the outcome of matches. In addition, football associations like the FAW and FA actively promote the “physical, tactical and psychological” training model during their coaching courses. This gives developing coaches a greater understanding of the role S&C practices play in supporting overall athlete development. Lastly, I believe the increasing influence of academia in sports science, S&C, and medical roles will naturally increase the knowledge and impart this knowledge onto players.

I am now in a fortunate position where I am able to undertake a PhD whilst working and utilising the resources (namely professional players) available to me in my day-to-day job. As a result of this portfolio of work, I can hopefully apply these findings to the players at Cardiff City to enhance the S&C provision at the club and promote these findings to hopefully help others working in professional football. Undertaking this PhD has allowed me to develop as a researcher and practitioner. As a researcher I have learnt to develop and execute a research methodology and framework that has led to the completion of this portfolio. I have learnt to critique current literature and ideas of practice in far greater depth than I may have previously. This has resulted in me questioning what segments of research I can truly utilize in my applied practice of day-to-day S&C in professional football. This enhanced critical awareness does not mean that I have to completely disregard research results that are seen in non-professional footballers, in different sports, or in a controlled lab environment, but that I have learnt to evaluate the potential effectiveness of these results to my specific demographic and working environment. I have gained valuable experience working collaboratively with some exceptional academics, researchers and practitioners during the course of my PhD studies. I have enhanced my knowledge in areas I thought I was

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competent on, and developed a greater understanding of areas I was previously not confident in, such as statistical analysis. I am grateful for everyone who provided their time to assist me, as this has made me a far better researcher than I was at the start of my PhD.

Critically, my journey and experiences have had a positive effect on a range of practices in my coaching programmes. Importantly, it has given me confidence to enhance our strength program to help reduce soft tissue injury risk. As a result, we now micro-dose and periodise a strength programme, rather than a specific titled "injury prevention programme", to improve our physical performance and reduce risk of injury. Players are now exposed to more frequent strength training stimuli, before and after training, and post-matches. This is a direct result of demonstrating that a traditional strength training programme can help reduce non-contact, soft tissue injuries (project 2), and that exposure to strength training during the season including periods of fixture congestion can help improve posterior chain force production (project 3). In addition, the suggestion that consistency in compliance to the programme may be just as, if not more important to the reduction of injury or improved performance is something that has also had a positive effect on my practice. This is a really interesting topic that would benefit from further research: understanding how coaches create the buy-in from players and staff to ensure consistency to the programme.

Finally, I feel I have helped a number of staff and interns develop their careers and understanding of what is required to work in professional football. Specifically, the body of work illustrated in this portfolio has influenced my philosophy, coaching methodology and practice at Cardiff City, with greater compliance towards S&C, a positive reduction in injury rates, and understanding of each player's individual physical responses across a full competitive season.

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2.3 Summary and Aims of Research

The overarching aim of this portfolio was to evaluate the application of S&C practices within elite senior football. Furthermore, the aim was the evaluate current strategies and provide evidence on how to plan and implement new strategies that could be useful in professional football. Thus, this portfolio aims to investigate the following:

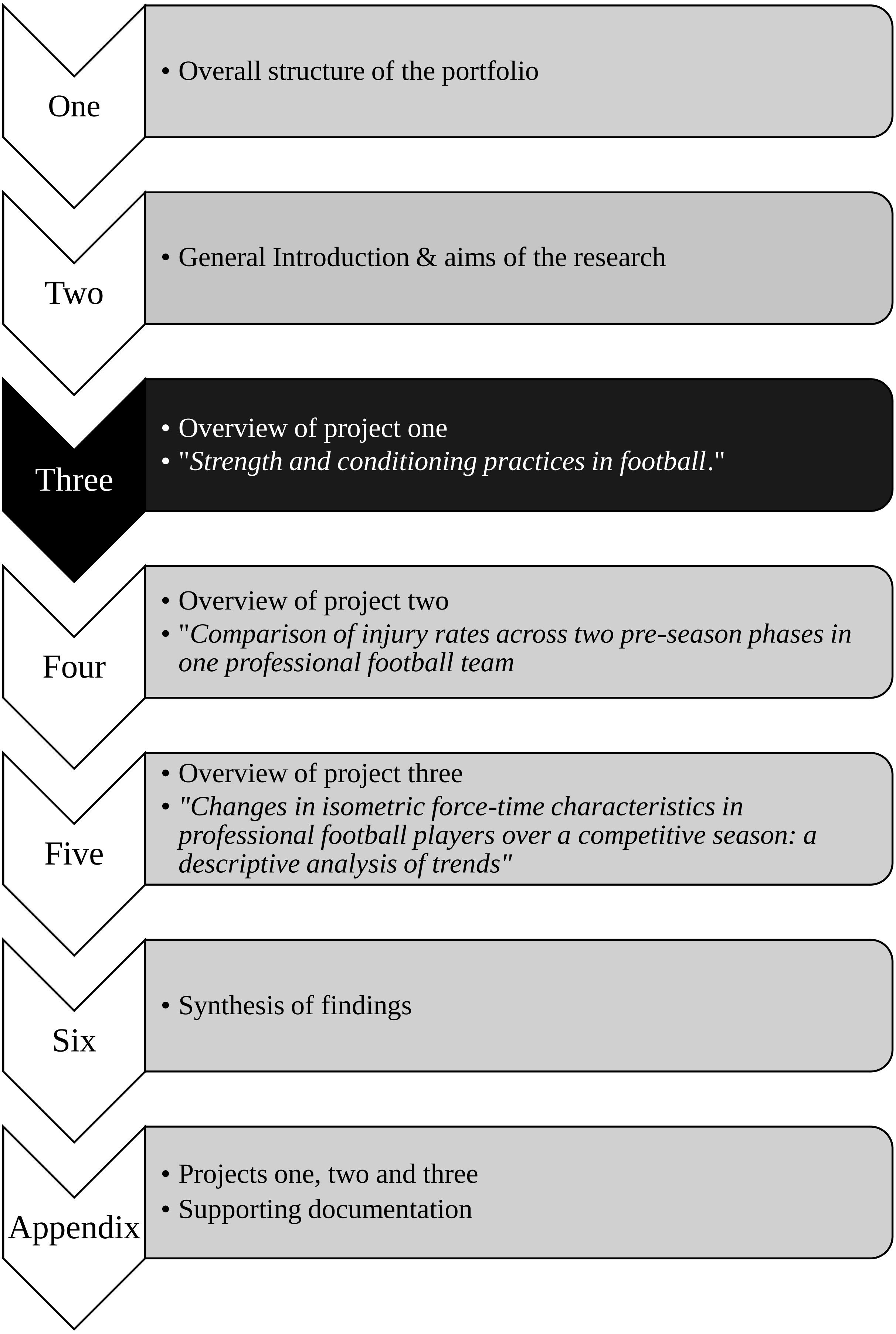
1. The current S&C practices, provision and challenges in elite football S&C (Project 1)

2. How S&C practices may influence the incidence, severity and injury rates during the pre-season phase of elite football (Project 2)

3. The changes in isometric force and rate of force development output across a full competitive elite football season (Project 3)

4. Evidence to demonstrate how the principles of S&C practices can emerge from research and be integrated into practice.

5. A critical discussion of the links between research and practitioner professional practice/ experience within elite senior football, which provides the reader with a critical overview of the portfolio.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CHAPTER 3

STRENGTH AND CONDITIONING PROVISION AND PRACTICES IN ELITE FOOTBALL

Findings from this project were published as two separate papers in a peer-reviewed journal

1a) Beere, M and Jeffreys, I. Strength and Conditioning provision and practices in elite male football. *Professional Strength and Conditioning Journal* 27-33, 2020.

1b) Beere, M & Jeffreys, I. Physical testing and monitoring practices in elite male football. *Professional Strength and Conditioning Journal* 27-33, 2021.

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3.1 Background

Football is the world's most popular sport with the Federation of the International Football Association (FIFA) estimating that more than 270 million people are actively involved in the sport worldwide (Turner, & Stewart, 2014). In recent years there has been a remarkable expansion in, and acceptance of, sport science (SS) and strength and conditioning (S&C) practices within football (McCall et al., 2015b). Strength and conditioning is a discipline that is recognised as a valid area of scientific and professional practice, with S&C practitioners' increasingly becoming key members of the multidisciplinary coaching team (McCall et al., 2015b). In light of the accepted importance of physical conditioning today, many teams hire S&C coaches to help prepare athletes for performance and to avoid injury (Durell et al., 2003; Jeffreys & Moody, 2016). Football is a highly challenging sport to support. In addition to the necessary technical and tactical skills, football players must develop and maintain a high level of athleticism to be successful and can require different, and in some cases, contrasting physical qualities for successful performance.

The availability of the literature quantifying the physical demands of elite football has allowed practitioners to gain a greater understanding of the physiology of football and thus potentially programme more effectively for their athletes (Morgans et al., 2014). The required increase in physical demand for successful performance is demonstrated with the year-on-year increase in match play intensity in English Premier League matches (Bradley et al., 2015). High levels of strength, power and endurance will be required to sustain the increased distance covered, number of sprints and high-speed running actions performed (Barnes et al., 2014). However, despite the increased input from S&C and SS practitioners', and the potential to enhance practice, there remains a challenge in fully integrating this work into the practices of football at multiple levels. This situation is often exacerbated by a lack of understanding of the roles that S&C coaches play and the practices utilised within the game.

Over the past decade there has been a surge in football related information in the field. This has involved multiple fields including monitoring of on-field training practices (Morgans et al., 2014), injury prevention (McCall et al., 2015a; McCall et al., 2015b; Owen et al., 2013), fatigue monitoring (Thorpe et al., 2016), return to play criteria (Taberner & Cohen, 2018; Dupont et al., 2010) and training load (Malone et al., 2015). However, whilst these areas have received plenty of review, there appears to be a relative dearth of research that has explored the function of traditional S&C practices, and even less concerning the practices, strategies and periodization used by S&C professionals in elite male football.

Physical performance testing is an integral component of an elite football players development programme (Hulse et al., 2013; Manson et al., 2014). The key role of a strength and conditioning (S&C) coaches' role is to help improve physical performance and reduce injury rate (Beere et al., 2020). While designing training programmes appears to be the first step of training management, monitoring the impact of the sessions on players appears to be the second important step towards being successful in the training process (Djaoui et al., 2017). As part of the efforts to maximise performance and minimise injury occurrence, S&C coaches and medical staff will frequently engage in multi-dimensional strategies aimed at the monitoring of player wellness, training load, physical status, strength and readiness to train on a daily basis (McCall et al., 2015b; Thorpe et al., 2016).

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While research has shown how monitoring one measure can highlight an athletes training response or readiness, it is currently unknown what, and how frequently assessments are used within the elite football environment. Furthermore, it is also unknown if assessments of performance such as speed, muscle strength, change of direction or aerobic capacity are tested throughout the season.

S&C practices have been examined in numerous other sports including Basketball (Simenz et al., 2005), Ice Hockey (Ebben et al., 2004), American Football (Ebben et al., 2001) Rugby Union (Jones et al., 2016), Rowing (Gee et al., 2011), Baseball (Ebben et al., 2005) and Cricket (Pote et al., 2016). However, there is very limited available data detailing how S&C professionals operate in elite football. Research in football has typically focussed on injury prevention methods in international Premier League clubs (McCall et al., 2015a), during international competition (McCall et al., 2015b) and during the return to play/perform process (Dupont et al., 2010). Unfortunately, there is currently no data regarding specific details on methods of application such as session distribution, session frequency and periodization strategies; staff structure; methodologies utilised, programming rationales, and session compliance. Similarly, there is no clear understanding of the logistical challenges facing S&C coaches such as the impact of match schedules on programming, the impact of the coaching team and how these challenges faced at the elite professional level impact the implementation strategy of the S&C coach. In addition, information regarding how practitioners' over-come the challenges faced in day-to-day delivery of S&C programs has never been reported. To date, there is only one research paper that highlights the potential skills required by S&C coaches in football (Springham et al., 2018). This research comments on the requirement to bread coaches who can communicate with players and coaches, and not just be driven by data, and provides a potential needs analysis framework for the next generation of S&C

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coaches. This information is invaluable, but it is only the authors opinions (as a result of years in practice) rather than feedback from a larger source of S&C coaches.

Therefore, in order to examine a variety of S&C practices and determine the common and the unique practices employed in elite male football, an online survey was designed and disseminated to practitioners' working in senior male football. Information obtained from this research will allow coaches access to a serviceable source of the collective ideas of others that they can use to compare with their own provision, and potentially incorporate into, their own practices. In addition, it will add to the information previously reported into the potential interpersonal skills required to develop as an S&C coach in football (Springham et al., 2018). At this time, no source of information exists for S&C training methods in football. This information may also help inform training programme design for future studies seeking to examine the influence of S&C interventions in elite football players.

3.2 Aims and Context

Project one aimed to produce a research manuscript that:

a) Examined the demographics, staff structure and qualification status of S&C practitioners' working in elite senior football;
b) examined the practices and provision of S&C training in elite senior football
c) examined the barriers S&C coaches face implanting practice;
d) examined the use of technology and monitoring practices in elite football;
e) examined the issues practitioners' have with current research in the field of S&C;
f) examined the current patterns and trends in injury rates;

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g) examined practitioners' opinions on why injury rates are currently still high in professional football; and
h) opinions on the future of S&C in football

Due to the vast amount of information obtained from this survey, three separate manuscripts were produced; with two parts being published in a peer-reviewed journal. The third, part one c, is in the process of being edited for publication.

3.3 Key Findings and contribution to the field

This was the first reporting of S&C practices in elite male football. Therefore, key findings and contributions of this project (part a, b, and c) are as follows:

- There is now the largest survey of professional S&C coaches in a single sport available in a peer-reviewed journal, and for the first time, information regarding practices in football.
- Many practitioners' deliver the same type of exercises with their players, with a dual focus on bilateral and unilateral exercises. The top 5 most commonly utilised exercises are; 1) hex bar deadlift, 2) Romanian or stiff leg deadlift variations, 3) barbell squat, 4) rear foot or split stance squat variations; and 5) Nordic hamstring curls.
- Practitioners' prioritise performance enhancement strategies over injury prevention strategies.
- It is a common programming strategy that players do the same compulsory exercises, but have specific individual extras.
- Many practitioners' use the same monitoring tools (GPS, body composition, heart rate response and player wellness) with their players.

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- Monitoring practices are governed by the need for non-invasive and less time-consuming, quick and efficient tests.
- An average of 9.8 monitoring assessments are used during the in-season period.
- Coaches have shown that communication and "building trust and effective relationships with players" are considered more important for creating player buy-in to the programme.
- 94% of coaches believe there has been a positive change in attitude from players towards S&C practices during their time working in football, but the questioned is raised *"is this because the players are more conditioned to just do as they are told?*" (participant 14).
- Practitioners' feel that there is not enough research available in the literature that is "practical, real-world based" and "not suitable to our environment".
- Current practitioners' feel that the future of S&C in football "*will take a big role in rehabilitation*"(participant 18); *"the increased demands of the game and athletes will improve buy-in"* (participant 8*);* and "*with players becoming fitter, faster, stronger, the role of the S&C coach will become more vital"*(participant 42*),* but suggest that "*strength coaches need to understand that there is more than just the gym, and getting stronger being the only answer"* (participant 31); *"best practitioners' are leaving the game due to undervalued salaries*"(participant 23*),* and *"isn't the same career support pathways as there is with technical coaching"* (participant 22).
- This study provides new evidence that practitioners' in professional football can use to review current practices and also provide new ideas for diversifying/modifying future practices. In addition, graduates or S&C coaches wanting to work in professional football may tailor their continued professional development to align with contemporary practices outlined.

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It should be noted that since publication of my two papers, and during the period of writing this PhD portfolio, another survey into the practices of S&C coaches in football was published (Weldon et al., 2020). However, my research was still the first to address this area and to be published in elite male football. In addition, the research by Weldon et al., (2020) follows the exact format of the initial body of research into S&C practices in other sports (Ebben et al., 2001; Ebben et al., 2004; Ebben et al., 2005). Therefore, it is in my opinion that my questionnaire provides far greater breadth and depth of feedback than the subsequent Weldon et al., (2020) research.

3.4 Author's contribution to the evidence

My contribution to project one was as follows:

(a) I designed both studies, including the aims, procedures and sampling of the participants;

(b) I led the data collection and data analysis procedures, using the co-authors as critical friends to ensure that the data had been collected and analysed thoroughly and appropriately;

(c) I wrote the manuscripts, designing the way in which the findings would be presented and engaging in the critical discussion to detail the implications of the research; and

(d) my co-authors supported each stage of the process with guidance and clarity as well as editing the manuscripts once they had been prepared.

3.5 Links to Project Two and Three

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The evidence emerging from project one helped provide supporting rationale for the value of project two and three. Fundamentally, results indicated that the S&C practitioners' role involves injury prevention (project two) and performance enhancement (project three).
The survey asked practitioners' their opinions and experiences regarding current published strength and conditioning and medical research. When asked about their opinions regarding current S&C research, 62% of coaches feel that too much research is clinically based and not always applicable to the real world situation, while 33% stated there is not enough research published using the level of athletes we work with and there is not currently enough practical day-to-day research being published.
Given the responses to the questions in project one, practitioners' feel that scientific research is often overlooked in daily practice due to it not being applicable to the environment of professional football. In addition, results from this survey have shown that coaches follow the recommended advice given in the literature when they feel it can be applied to their organisation. It can therefore be suggested that for a greater uptake of research driven practices, S&C research needs to highlight how procedures can be implemented into a day-to-day environment to suit the needs of the coaches. Project two is an intervention study and project three is a trend analysis of practices that took place in an elite environment, and thus the findings could be further applied to other practical settings.

It appears imperative that the results / queries detailed in study one of this project should be listened to and thus attempted to be answered with projects two and three to ensure that coaches have the required information to draw knowledge from to potentially better manage their own athletes.

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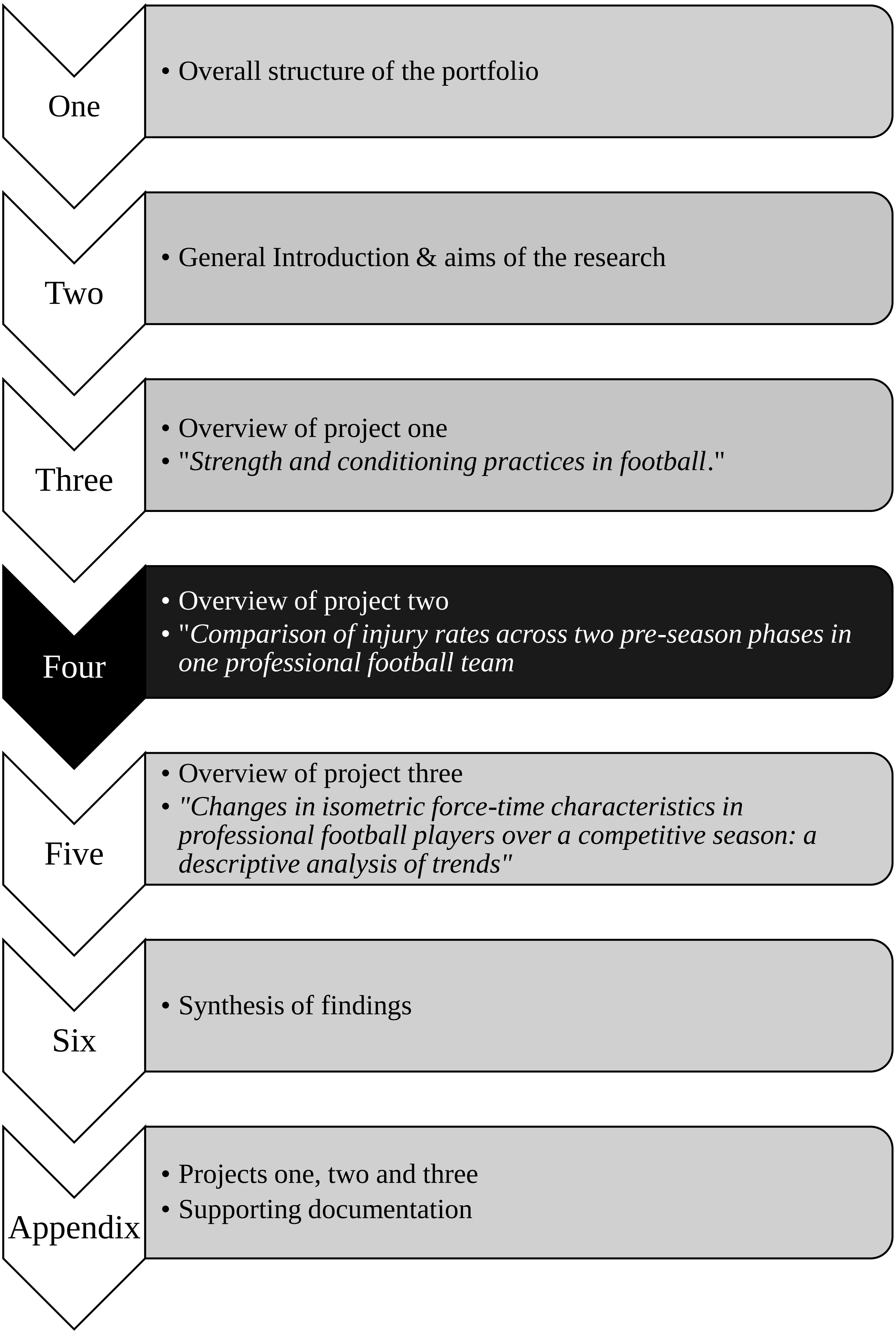
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CHAPTER 4

COMPARISON OF INJURY RATES ACROSS TWO PRE-SEASON PHASES IN ONE PROFESSIONAL FOOTBALL TEAM

4.1 Background

The influence of injuries in professional football is significant, with relationships between reduced injury rates and improved team performance (increased average points per game and higher league ranking*)* being evident (Hägglund et al., 2013). Due to the negative effects that injuries have on team performance (Hägglund et al., 2013), the large financial cost (Ekstrand et al., 2013), and long-term player health (Turner et al., 2000), injury prevention strategies are seen as an essential part of sports performance (Fanchini et al., 2020). Results from paper one (page 86) show that injury prevention is an important component in strength and conditioning programming in elite football.

Although the cause of injury is not always known, and can be multi-factorial in cause (Bittencourt et al., 2016), there are a number of potential factors that may increase its incidence. Injuries are often related to non-modifiable and modifiable, and intrinsic and extrinsic factors. Non-modifiable factors are those that cannot be regulated or altered by the practitioner, such as athlete age, sex, and injury history (Parry and Drust, 2006). Modifiable factors that include player training load, warm-up preparation, muscular imbalances and neuromuscular strength deficits (Buckthorpe et al., 2019; Bahr et al., 2005) can all be targeted with interventions and regulated by the practitioner.

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Two of the biggest modifiable risk factors are neuromuscular strength and training load. Reduced strength, strength asymmetry and a strength ratio imbalance between muscles are key risk factors for muscle injury (McCall et al., 2015; Volpi et al., 2016; Read et al., 2016; Read et al., 2019). Current evidence across team sports indicated that load, in terms of player exposure and /or exertion, could either be an independent protective- or risk factor for injury (Gabbett et al., 2016). This will depend on whether load administration is optimal and progressive, or sub-optimal with rapid increases thus creating a "load spike" (Gabbett, 2016; Malone et al., 2019; Gabbett et al., 2016; Bowen et al., 2017). Available evidence suggests that avoiding a spike in load (e.g., working within the parameters of the acute to chronic workload ratio) is associated with less injuries in elite football (Bowen et al., 2017; Malone et al., 2016). Therefore, the individual and collective relationship of athlete strength and training load should be examined to determine if injury rates can be affected with appropriate exercise based strategies.

4.12 Injury prevention models

During recent years, there has been, and continues to be, an influx of published research in the injury prevention domain, including the development of models and framework to guide prevention (van Mechelen et al., 1993; Finch 2006; Meeuwisse et al., 2007; O'Brien et al. 2018), with many practitioners' looking to this research to guide and enhance their practice (project 1C). However, many existing models are centred around the conduct of injury prevention research and do not reflect the everyday injury prevention approach of practitioners' working in professional teams. Initially, Finch (2006) introduced an extension of the van Mechelen (1992) model called the Translating Research into Injury Prevention Practice (TRIPP) framework, which emphasises the key role of implementation aspects in

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achieving real-world injury prevention strategies. To further this work, O'Brien et al., (2018) presented a new model, the Team-sport Injury Prevention (TIP) cycle, which was specifically aimed at the practitioner working in professional sports. It involves a simple continual cycle with 3 key phases (see figure 4.1): (Re) evaluate; Identify; and Intervene. By progressing through the model's three phases, practitioners' can develop context-specific and dynamic injury prevention strategies.

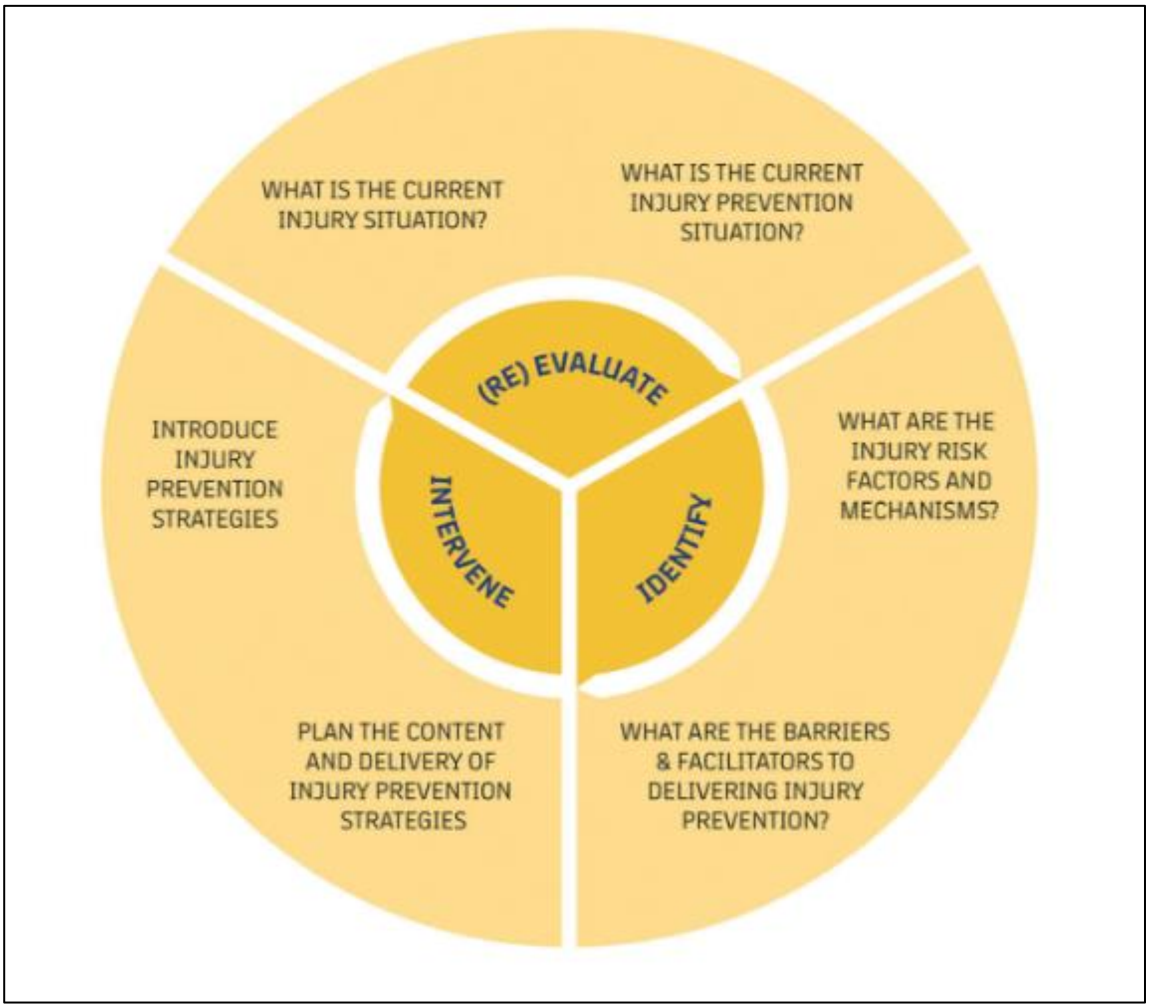

Figure 4.1. The Team-sport injury prevention (TIP) cycle proposed by O'Brien et al., (2018).

Exercise-based strategies in the form of injury prevention exercise programs (O'Brien et al., 2016) are frequently and importantly perceived strategies implemented by elite football teams

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aimed to reduce the risk muscle injury (Beere & Jeffreys 2020; McCall et al., 2015). Programmes such as the FIFA 11+ (Soligard et al., 2008), the Prevent Injury and Enhance Performance programme (PEP) (Steffen et al., 2008), and Sportsmetrics (Mandelbaum et al., 2005) have been previously designed and proven effective in preventing sports-related injuries. The FIFA 11+ programme has shown to induce a substantial injury-preventing effect by reducing adductor injuries when compared to control protocols (Thorborg et al., 2017). The PEP and the Sportsmetrics programme are two programmes that have been shown to significantly reduce ACL injury rates and improve athletic performance (Noyes and Westin 2012). However, there is a question as to whether a specific injury prevention programme would be superior to appropriately dosed general training (Plummer et al., 2019; Lauersen et al., 2018).

4.13 Strength training

Among all exercise-based strategies traditionally proposed in research to reduce injuries, strength training has consistently shown to have the greatest benefit in reducing acute and over use lower limb injuries (McCall et al., 2015, Brunner et al., 2019, Bahr et al., 2015) with a positive dose-response relationship between strength training and injury prevention being previously reported (Lauersen et al., 2018). A recent meta-analysis (Brunner et al., 2019) showed that ten of the eleven programmes analysed which comprised mainly of strength training were shown to be effective in reducing overall injury rate, concluding that lower limb strength training exercises should be prioritised in strategies aimed at reducing the risk of injury. In addition, well-developed lower-body strength has been associated with a greater tolerance to higher workloads as well as a reduced risk of injury in team-sport players (Malone et al., 2018). With the increase in workload and intensity in professional football

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(Barnes 2014), increasing a players tolerance, resilience and resistance to injury via strength training methods would be very beneficial to a strength and conditioning practitioner.

4.14 Training load

Together with muscle strength, overall training load has been proposed as risk factors for future injury (Gabbett et al., 2012; Eliakim et al., 2018; Ekstrand 2013). The interaction between workload, injury and performance is central to managing athletes in team sports, such as football (Eirale et al,2012; Hägglund et al., 2013). It has been highlighted that a reduced absolute training load significantly reduced injuries among youth and adult professional players (Watson et al., 2017 ; Bowen et al., 2017).

Traditionally, workload-injury investigations focused on absolute workloads and injury (Killen et al., 2010) and higher workloads were associated with greater rates of injuries (Gabbett, 2004). However, high training loads are necessary for beneficial physiological adaptation such as increased aerobic capacity, strength and repeat sprint ability (Tønnessen et al., 2011) many of which are associated with decreased injury risks (Gabbett et al., 2012). Recently, load-injury investigations have highlighted that the relationship between acute 1-week and chronic (rolling 4-week total averaged to 1-week) workloads, termed the acute: chronic workload ratio, may better predict injury risk than total workloads (Hulin et al., 2016) and may help reduce injury rate in football (Bowen et al., 2017). While understanding how changes in training load can have a positive or negative effect on injury rate, it is very rare for research to be able to compare two periods of time with a matched training load. One of the aims of project two was to try and demonstrate that training load is matched between two pre-season phases. This will potentially give greater ecological validity and support to the effect strength training has on injury rates.

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4.2 Pre-season training phase

In football the season is typically divided up using a phasic model of periodisation based around an off-season, a pre- season and a competitive season (Silva et al., 2015). The off-season has been defined as a period of the year combining active rest and individual preparation prior to the start of scheduled technical and tactical training (Gamble, 2006). The pre-season involves concurrent technical and tactical practice and features a high intensity regime of physical training targeting multiple, football related components of fitness (Faude et al., 2013; Calleja-Gonzalez et al., 2020). There will often be progressively more match like practices and this period may feature some full matches which are outside the clubs' competitive league or cup fixtures. Although the pre-season phase is relatively short (5-6 weeks) (Ekstrand et al., 2020), it is considered a critical training period for professional football athletes. The aim of this phase is to develop key physical characteristics (e.g. aerobic conditioning, strength, power, speed) whilst match play requirements remain low. The competitive season can be considered the period of the year where the team are actively involved in league or cup fixture schedules. It is likely to feature frequent competition and a reduction on conditioning volume (Gamble, 2006). It is well known that football schedules are often chaotic in nature and constantly changing.

Pre-season training provides several physical benefits for professional football teams. It can allow players to reach high chronic workloads (Hulin et al., 2016), as well as develop the physical capacities associated with reduced injury risks (Gabbett et al., 2012). Indeed, proper high load pre-season training is reported to decrease the risk of injury (Gabbett et al., 2018; Wind et al., 2017).

It has recently been shown that players who have a more ‘successful’ pre-season, and complete more sessions may be more resilient to injury when faced with the demands of the competitive season (Ekstrand et al., 2020). Understanding the benefit of pre-season training, not only on the short term pre-season phase, but also on the in-season injury patterns may help inform practitioner planning and preparation.

Collectively, if strength and conditioning practitioners’ can increase the tolerance to high workloads and reduce the risk of injury during the pre-season phase with strength training practices, thus allowing the athlete to complete more training sessions, then it may also have positive effects on in-season injury rates and team performance. Therefore, it was investigated whether elite football players who participated in pre-season strength training sessions were at lower risk of injury, while accounting for their external training loads, during the pre-season phase.

4.3 Overcoming the challenges in applying injury prevention research in professional football

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There are several challenges associated with research into professional football. These can include inadequate subject numbers, the inclusion of a matched-control group, and a variety of external variables that may interfere with any planned intervention. These may include changes in fixture schedule, changes in management, changes in training load, injuries to players acting as subjects, the transfer of players to another club, and overall team and player compliance to a programme. The ability to control these variables is difficult and thus provides a challenge when trying to compare intervention based studies in this environment.

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The research conducted in project 2 reports data from two 6-week pre- season phases from one professional senior, male football team. The resultant information will be compared to assess the impact of a structured lower limb strength training programme on injury rates. Pre-season 1 (2017-2018) will act as a control, and pre-season 2 (2018-2019) will act as the intervention group. The intervention was added during the second season due to the senior management changing their approach to strength and conditioning practices during pre-season phase. This was partly due to an increase in competition standard (promoted from the English Championship during 2017-18 to the English Premier League for 2018-19 season). Unlike previous comparative studies where either the injury prevention programme was removed during the second season (Owen et al., 2013); the intervention has no control group (Zouita et al., 2016); or the intervention was different between groups within the same squad of players (Rønnestad et al., 2011), this projected aimed to provided us with a unique situation in professional sport and thus increased the ecological validity of the findings.

As discussed, improved neuromuscular capacity, control, and strength are protective against injuries among football players (McCall et al., 2015; Volpi et al., 2016; Read et al., 2016; Read et al., 2019). Additionally, current evidence suggests that training load management is a viable target for mitigating injury risk in football (Bowen et al., 2017). Therefore, the aims of the current investigation were two-fold. First, we aimed to assess if training load was similar between the two consecutive pre-season phases. This would allow for a greater, more accurate comparison of the pre-season phases. In addition, this would provide a unique understanding of the potential effectiveness of strength training on injury rates. A secondary aim of the intervention was to explore the effectiveness of a strength training programme on the total number, rate, and severity of muscle injuries. The unique aspects of this study were; 1) only the athletes (n= 20) who completed both pre-season periods were included in the analysis; 2) we aimed to show that training load, number of training days, and number of

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non-competitive matches were similar between the two pre-season phases; and 3) there was no enforced removal of an intervention, which is often difficult to achieve in professional sport research

4.4 Aims and Context

In attempts to address the needs established previously, project two aimed to produce a research manuscript that:

a) examined the impact of a structured strength training programme on soft tissue injury rates between the same group of players across two consecutive pre-season phases
b) examined how traditional strength training methods, can be implemented during a pre-season phase in professional senior male football; and
c) examined the impact of a structured strength training programme on soft tissue injury rates when other training load, schedule and physical variables were the same between pre-season phases

4.5 Key Findings and contribution to the field

The key findings of this project are as follows:

- The inclusion of a strength training programme can reduce soft tissue injury rate (per 1000hrs) by 50% in the same cohort of professional football players
- The inclusion of a strength training programme can reduce the number of days lost to injuries by 60% in the same cohort of professional football players
- The inclusion of a strength training programme may reduce the severity of injury in professional football players
- This is the first study (to the author's knowledge), that can provide a comparison of the overall training load during two pre-season phases (total distance, distance covered

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above 5.5 m/s, and total duration) whereby no statistical significant difference was seen. This allowed the comparison of a control vs intervention group in a manner that is rare in professional sport.

- Compliance of players to the strength training programme was high (76%), and this maybe just as important to the reduction in injury rates as the content of the sessions itself
- The information provided in this study can help coaches become more knowledgeable about including strength training into a pre-season phase that may help reduce soft tissue injury rate

It should be noted, that while this study shows a reduction in rate and severity of injury, this study is only reflective of one team (albeit a team competing in the English Championship and Premier League) and during a specific phase of the season (pre-season) and hence may not be representative of the customary training demands of other domestic teams or those from other countries that may be influenced by different managerial and coaching philosophies. As such a number of a number of limitations that may prevent the generalisation of the results are highlighted (see page 189).

4.6 Author's Contribution to the Evidence

My contribution to project one was as follows:

(a) I designed the studies, including the aims, procedures and sampling of the participants;

(b) I led the data collection and data analysis procedures, using the co-authors to ensure that the data had been collected and analysed thoroughly and appropriately;

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(c) I wrote the manuscripts, designing the way in which the findings would be presented and engaging in the critical discussion to detail the implications of the research; and

(d) my supervisors supported each stage of the process with guidance and clarity as well as editing the manuscripts once they had been prepared.

4.7 Links to Project One and Three

This project have provided supporting rationale for the value of project one and three. Results from project one indicated that the S&C practitioners' role involves injury prevention and performance enhancement. The role of the S&C practitioner in prevention of injury significant as injury rates are still high within professional football, which can be of a financial and performance detriment to the club. Results from the survey in project one highlight that practitioners' are still concerned by the growing rate of injury occurrence in professional football. Understanding how a strength programme can help reduce injury rates is therefore invaluable for the practitioner. The resultant information may add to the knowledge from to potentially better manage their own athletes.

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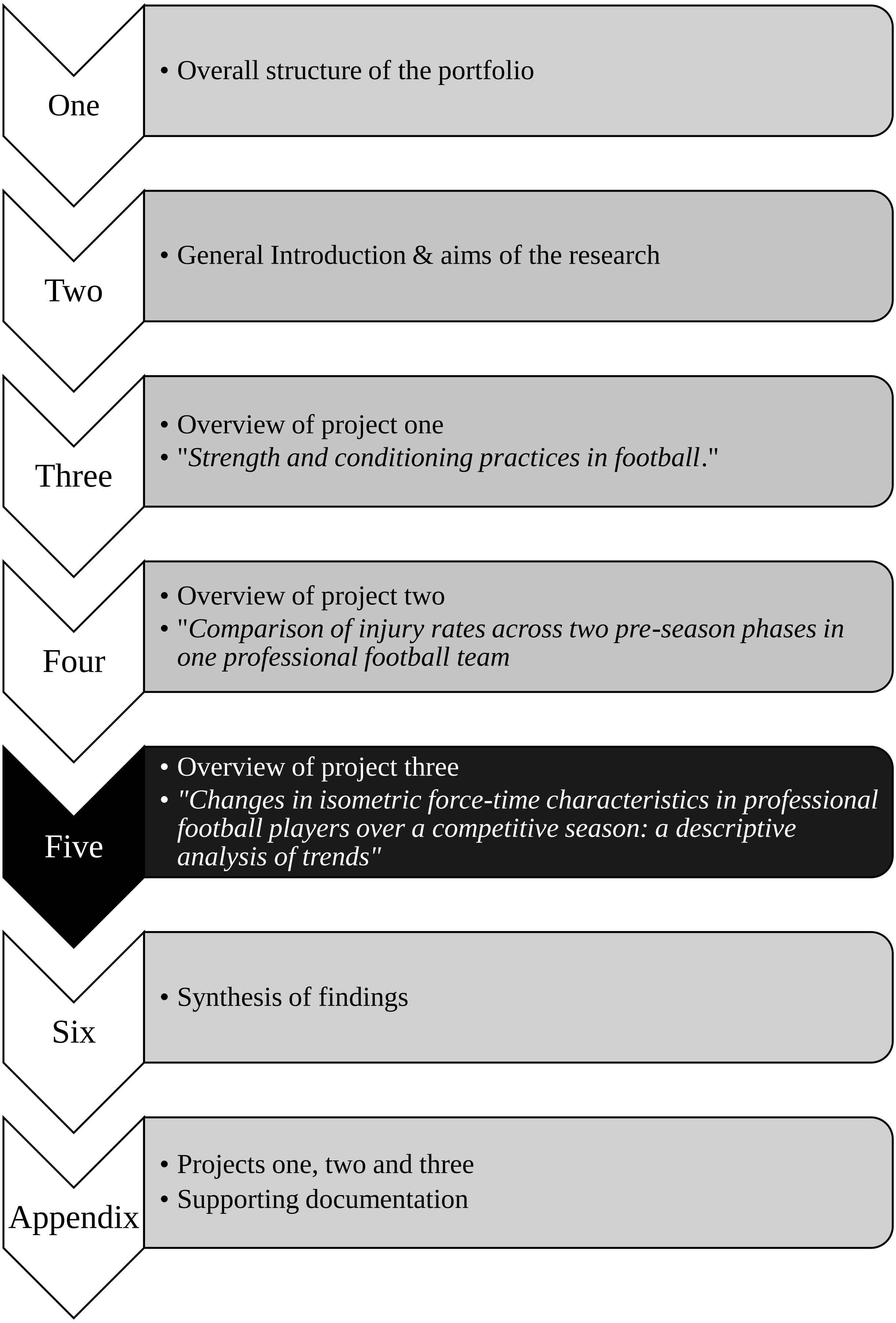
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CHAPTER FIVE

Changes in isometric force-time characteristics in professional football players over a competitive season: a descriptive analysis of trends

5.1 Background

Elite football players compete over long competitive seasons, with multiple games per week (Meckel et al., 2018; Dellal et al., 2013). Given that decisive games with larger consequences, such as play-offs, knockout stages of competitions or cup finals, often take place at the end of the season it is vital that key physical qualities are maintained, performance is high, and injuries are minimised throughout the entirety of a competitive season. Strength and conditioning practitioners' must therefore strike a difficult balance between training to improve performance capacities and providing adequate rest and recovery to ensure optimal performance on a weekly or bi-weekly basis. In order to understand how best to prepare their athletes, S&C practitioners' within football must understand how key physiological characteristics such as strength and rate of force development (RFD) are likely to change over a full season. In addition, S&C practitioners' should also be aware of which factors are likely to impact the development or maintenance of such qualities.

5.12 Changes in physical performance characteristics during a season

The basic demands of many sports require athletes to rapidly exert high forces to accelerate, decelerate or change direction (Suchomel et al., 2016; Cormie et al., 2011; Fraude et al., 2012; McBride et al., 2009; Wisløff et al., 2004**).** Resistance training, focussed primarily on

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the development of strength, is critical for improving athletic development and underpins both individual and team sport performance (Suchomel et al., 2016; Suchomel et al., 2018). In elite football, strength development is frequently prioritised by practitioners' aiming to improve performance and prevent injuries (Beere & Jeffreys, 2020 / Project 1a/ Walden et al., 2020).

The existing literature in the field of S&C contains an increasing volume of evidence regarding the application of S&C programming in football (Owen, et al., 2013; Turner & Stewart, 2014; Comfort et al., 2014; Zouita et al.,2016). However, it is important that the outcomes of these studies are viewed within the context of the professional male football environment. Research of S&C practices in football are often limited to smaller time frames (e.g. 4-12 week blocks (Bogdanis et al., 2009; Rønnestad et al., 2011), Academy aged players (Bishop et al., 2020; Emmonds et al., 2018; Zouita et al., 2016) or focussed on managing injury rates (Owen et al., 2013; Zouita et al., 2016). Whilst these studies have importance, the results may not reflect the adaptation potential of well-trained professional football players, where the concurrent training environment, the principle of diminished return, and the time-limited nature of a competitive season are all factors which make athletic development harder to achieve (Argus et al., 2009, Cormie et al., 2010b, Crewther et al., 2013). For example, it has been shown that improvements in muscular strength and power are achieved with relative ease in short term studies in untrained individuals (Cormie et al., 2007a, Comfort et al., 2020). However, while the findings from Comfort et al., (2020) are of interest, the study of 2 x 4 week meso-cycles means that these findings cannot be extrapolated to a full, 38 week professional football season, whereby fatigue and performance interact when these cycles are periodised sequentially. Consequently, a greater knowledge of the strength and RFD characteristics associated with continuous periodised meso-cycle blocks within different phases of a professional season (e.g., pre-season and in-season) is

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required if effective and efficient S&C practices are to be incorporated to allow increased physical development in professional male football.

Due to the increased demands of technical training and competition, in-season S&C programmes are often designed to maintain adequate levels of strength and power over several months that have been developed during the pre-season period (Rønnestad et al., 2011; Eniseler et al., 2012; Gannon et al., 2016; Turner 2011; Turner & Stewart., 2014). Rønnestad et al., (2011) demonstrated that strength training once per week over the first 12 weeks of the in-season permitted the maintenance of strength when compared to one session every two weeks. This has led some reports to state that the aim of in-season training should be to maintain, rather than increase strength and / or power levels (Turner 2011; Turner & Stewart 2014). For sports where there are regularly ≥ 2 games per week, and a large technical-tactical focussed approach, there would be a potentially detrimental long-term effect if athletes were not be able to maintain strength throughout a full season. Focussing on 'maintenance' is arguably a poor training goal during long seasons, especially given the fact that small but progressive increases in performance can be achieved in professional athletes (Baker, 2013). In addition, the 'maintenance' approach may disadvantage the developmental athlete such as those who need greater increases in athletic capabilities (e.g., young players transitioned in senior football) who, therefore, may never achieve their full potential as a result. Furthermore, it has been shown that injury rates are often greater during periods of the season where accumulated fatigue may be high; such as during congested fixture periods (Bengtsson et al., 2015; Dellal et al., 2013) or towards latter parts of the season (Ekstrand et al., 2011).

Despite the lack of data that currently exists tracking the extent and magnitude of adaptation during a full competitive season in professional senior football, beneficial increases in several parameters of strength performance have been identified in response to strength training during a Rugby Union (Appleby et al., 2012; Gannon, 2016) and Rugby League (Baker and Newton, 2006) season. However, it must be noted that there a different physical requirements for rugby, and in addition rugby is often played on a 1 game per week schedule, unlike football which often requires athletes to perform multiple times per week (Baker, 1998; Dellal et al., 2015) and therefore these results may not be applicable to football. Therefore, to help S&C practitioners' in football, similar longitudinal research needs to be produced with the professional football environment.

The available literature shows that force, and the ability to rapidly produce force are related to success in football (Silva et al., 2015b). At present however limited information exists regarding the changes in strength and RFD that occur during different phases of the season. Without information suggesting the direction and magnitude of likely changes in strength and RFD it is difficult for coaches to best plan their physical development strategy. Moreover, trends in RFD over the course of a whole season in professional football have never previously been reported. The limited findings of studies within football make clear conclusions regarding strength change during the competitive season difficult to draw. Furthermore, with only one study investigating strength change over a whole season in football (Eniseler et al., 2012), it is difficult for the practitioner to have a clear picture of the likely changes in strength over a competitive season in football. Given the duration of the season examined in this study (Eniseler et al., 2012) is around half of that typically seen in professional English competitions it is unclear how football players' strength characteristics are likely to change across a much longer competitive season. In addition, trends in physical performance over specific periods such as pre-season, the in-season or during congested period when the balance of match frequency and of strength and conditioning may vary substantially, have not been examined. Finally, despite the known changes in performance as

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a result of strength training in elite sport, very little research attention has been given to potential differences in physiological changes based on individual player responses in professional sport. Without knowledge of the way in which strength and RFD are likely to change and fluctuate over time, and the potential factors that may influence these changes, it is very difficult for practitioners' to develop optimal prescriptions for the maintenance and development of key physical attributes within football players.

5.13 Monitoring of neuromuscular function

The importance of monitoring assessments in professional football has previously been highlighted (Drust 2019, Beere & Jeffreys 2021; McCall et al., 2014; and Akenhead and Nassis 2016), whereby a multitude of monitoring strategies are often in place.
In a survey of practitioners' in elite football, Beere & Jeffreys (2021) (Project One B) reported that on average, 9.8 performance variables were measured during the pre-season, and 9.7 performance variables were measured during the in-season. The main reasons why practitioners' assess and monitor performance variables are to improve performance and to prevent injury (Akenhead and Nassis, 2016; Beere & Jeffreys, 2021) and manage training load (Akenhead and Nassis, 2016). There is particular interest in neuromuscular performance characteristics that can be screened for, and potentially addressed with effective training interventions. These could be inadequate hamstring strength (Timmins et al., 2015) and/or inter-limb strength imbalances (Bourne et al., 2015). To truly understand and evaluate the adaptation response to a training programme, multiple repeated measures of performance should be undertaken across a season (Mann, 2011). This may help the practitioner understand the trends associated with training, match play and strength loading that may appear during different phases of the season.

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Most research repeats measures of performance only twice; pre- and post- intervention; or a small number of times across the intervention period (Eniseler et al., 2012; Haugen et al., 2018; Bishop 2020; Emmonds et al., 2018; and Papadkis et al., 2015). Regular assessment of physical performance may provide more useful information to the practitioner to help inform decisions on training load, match participation, recovery strategies, alterations in strength training provision or warrant further examination of the athlete (Borresen et al., 2009; Kiely 2012). For a given number of subjects, relying on means from repeated assessments before, during and after the training intervention (instead of a single measurement) reduces the associated within-subject random variation. In other words, means of several observed values are a better estimate of the "true" value for an individual than a single observation.

5.14 Isometric posterior chain test

The monitoring of posterior chain strength has received increased attention in recent years (Bourne et al., 2017; Taberner & Cohen, 2018). Nordic eccentric strength and isometric posterior chain (IPC) strength testing are commonly employed measures of posterior chain strength in professional football (Beere et al., 2020, Project One A). Practical based research of the IPC strength test has become more common, as it can be implemented as part of weekly monitoring aimed at quantifying residual fatigue in the days following competition or return to play following injury (Schache et al., 2011; McCall et al., 2015; Wollin et al., 2018; Taberner & Cohen, 2018; McCall et al., 2014; Constantine et al., 2019; Nedelec et al., 2014). Isometric testing may provide an alternative method for monitoring and tracking neuromuscular strength changes in football players across the season as testing does not hold the same practitioner perception risk of DOMS as with the Nordic hamstring exercise (Beere and Jeffreys 2021: Paper 1b), and will provide different understanding of an athletes physical

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status compared to the often used CMJ. Furthermore, the IPC test provides information on maximum peak force production and RFD. This is important as RFD is an indicator of explosive strength and a neuromuscular quality that may better predict athletic performance (Harris, Cronin, and Keogh, 2007) than peak force in activities such as sprinting (Weyand et al., 2010), jumping (Cormie et al., 2010) and change of direction ability (Spiteri et al., 2013). To help promote the use of an easy to administer isometric test, Schache et al., (2011) described a 3-second isometric supine posterior lower limb muscle test performed in two supine positions: 90°:90° (knee: hip flexion) (90°:90°) and 30° (knee flexion). Both test positions have shown reliability and sensitivity to detect acute (McCall et al., 2015) and residual (Nedelec et al., 2014) fatigue following football match play. The importance of this test comes from the fact that lower levels of isometric strength in the hamstring muscles have been shown to be associated with increased risk of HSI, particularly when there has been a previous injury (De Vos et al., 2014).

5.15 Group and individual response to training

It has been suggested that the response to exercise training may not only differ between athletes (Bouchard, 2001; Mann et al., 2014), but also within the same person on different occasions (Mann, 2011). Within elite team sport, players might experience training loads that are either excessive or suboptimal, especially during in-season phases when increased or decreased involvement in training and matches occurs (Thorpe et al., 2017). Understanding individualized training responses therefore supports the requirement for frequent monitoring and reporting of changes in physical qualities (Buchheit, 2014). Whilst practitioners' have long understood there is variation in how their athletes respond to a given training stimulus, studies typically only consider the group response to an intervention to determine its overall

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effectiveness (Mann, 2011) and often only report such variation through the reporting of standard deviations or standard error. There is limited data highlighting the individual response vs. the group response to training in professional athletes, and therefore addressing this issue may further enhance the practitioners' knowledge of their athlete. Although reporting the mean and standard deviation within the group is a useful way to describe the variation in response, only viewing this may conceal a wide range of individual responses, such as high responders, non-responders and negative responders (Mann et al., 2014). In addition, it remains under-explored if the methods used to interpret group responses might be of any value to inform processes at the individual level (Buchheit, 2016; King et al., 2019).

Monitoring of neuromuscular strength is now commonly reported practice in elite team-sport settings (Beere & Jeffreys 2021; Project One B), where assessments of neuromuscular strength status may be used to inform the choice of subsequent recovery modalities or training stimuli. Therefore, a longitudinal understanding of how neuromuscular strength may vary over a season and an understanding of potential moderating influencers may be useful to S&C practitioners', where maintaining optimal neuromuscular strength status over a season offers a unique challenge. While research suggests that isometric modalities offer a viable alternative measure of neuromuscular strength , an understanding of the seasonal trends peak force and RFD measures collected from isometric assessment are lacking in football. It is therefore unclear the impact that a season long competition has on isometric rate and peak force measures. This project will aim to see if differences in isometric measures of force time characteristics (Peak force, mean peak force, and RFD) are evident across a football season.

Of further use to practitioners' is an understanding of factors that may moderate neuromuscular strength responses which may improve management of long-term athletic development for individual athletes. While it is likely that multiple factors influence short and long term training responses, of particular interest to the S&C coach is the influence of physical qualities such as baseline strength (peak and RFD). To this authors knowledge, there is a paucity of longitudinal research that examines the potential moderating influence of physical qualities on isometric force output, and how this creates different individual responses.

5.2 Aims and Context

In attempts to address the needs established previously, project three aimed to produce a research manuscript that:

a) Provides an in-depth analysis of trends in force and RFD production in elite male footballers that have previously not been reported across a competitive season

b) Highlights the differences in both group and individual trends that occur across the season that have previously not been reported.

c) Highlights the trends in isometric strength performance during different phases of the season as a result of multiple assessment points that have previously not been reported.

d) Highlights whether baseline physical qualities exert a moderating influence on seasonal isometric force outputs

5.3 Key Findings and contribution to the field

The key findings of this project are as follows:

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- Posterior chain isometric force output can be improved across a competitive football season. This is in contrast to the often reported need for maintenance of many physical qualities during a season.
- Posterior chain rate of force development can be improved across a competitive football season. This is the first time that RFD has been reported in footballers for this duration.
- This research is the first to examine the trends in isometric force and RFD output during different phases of a football season and relating the observed changes to periods of high or low fixture and S&C frequency/ density.
- The results also show the differences between viewing physical response changes from the group and individual level
- Baseline strength appears to affect the magnitude of individual response seen across the season and within specific phases; with athletes with lower baseline (LB-) strength having larger full season adaptations than those with a high baseline (HB-) strength, but with HB-strength having a reduced negative impact during congested fixture periods.
- Provides data from a reliability test for the use of the IPC 90-90 test in professional footballers

5.4 Author's contribution to the evidence

My contribution to the study (manuscripts) was as follows:

(a) I designed the study, including the aims, methodological procedures and sampling of the participants;

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(b) I led the data collection and data analysis procedures, using the co-authors to ensure that the data had been collected and analysed thoroughly and appropriately;

(c) I wrote the manuscript, designing the way in which the findings would be presented and engaging in the critical discussion to detail the implications of the research; and

(d) my co-authors supported each stage of the process with guidance and clarity as well as editing the manuscripts once they had been prepared.

5.5 Links to Project one and two

The information in this project have provided supporting rationale for the value of project one and two. Results from this survey indicate that the S&C practitioners' role involves injury prevention (project two) and performance enhancement (project three). Given the responses to the questions in project one, practitioners' feel that scientific research is often overlooked in daily practice due to it not being applicable to the environment of professional football. Projects two and three are both observations that took place in an elite environment, and thus the findings could be further applied to other practical settings.

It appears imperative that the results / queries detailed in study one of this project should be listened to and thus attempted to be answered with projects two and three to ensure that coaches have the required information to draw knowledge from to potentially better manage their own athletes.

Finally, the findings emerging from this project can help and have helped my own professional practice at Cardiff City, giving me greater understanding of the individual physical characteristics and responses to our training programmes.

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One
- Overall structure of the portfolio

Two
- General Introduction & aims of the research

Three
- Overview of project one
- "*Strength and conditioning practices in football*."

Four
- Overview of project two
- "*Comparison of injury rates across two pre-season phases in one professional football team*

Five
- Overview of project three
- *"Changes in isometric force-time characteristics in professional football players over a competitive season: a descriptive analysis of trends"*

Six
- Synthesis of findings

Appendix
- Projects one, two and three
- Supporting documentation

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CHAPTER 6

SYNTHESIS OF FINDINGS

6.1 Evaluation of aims and objectives

The overarching aim of this portfolio was to evaluate the application of S&C practices within elite senior football. This chapter summarises the results from projects one, two and three, and discusses the practical applications of these findings that may help inform the practices of S&C and physical performance coaches. Influencing these decision making processes may result in the efficient management of S&C practices for injury prevention and performance gain during different phases of a competitive football season. In addition, this chapter will highlight how the work conducted in this portfolio has impacted my working practice.

This portfolio of research has resulted in a number of theoretical and practical implications for S&C practices and professional development in elite football. My first contribution to the field is outlined in project one with a survey of S&C practices of those working in elite male football. At the time of writing and publication, this was the first conducted in football and the largest of any single sport. This project provided evidence not previously reported; highlighting when and how practitioners' aim to incorporate strength, plyometric, eccentric and speed development sessions into their training schedule. It also reports the variables that need to be considered, and barriers to incorporating practices when trying to include S&C practices. The follow-up study, project two, provided evidence to suggest that strength training may help reduce the incidence and severity of muscle injuries during a pre-season phase. While this in itself may not be a new contribution to the field, project two offers a unique methodology, as pitch based training load was controlled between the two comparable

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pre-season phases, with the addition that the same 20 players were used in both pre-seasons. Therefore, one pre-season acted as a natural control group vs. the intervention group in the second, allowing for direct comparison of the effect of strength training on injury rates in the elite environment. Finally, project three, provided new evidence regarding the adaptive changes in isometric force production across a competitive season that has never previously been reported in elite football. Of key importance was the demonstration that force characteristics (peak and mean force, and RFD) can be improved throughout the duration of a season. These findings are contrary to those previously reported whereby strength, force and power outputs are only maintained or reduced across a season.

6.12 Common trends throughout the portfolio

There are several common themes linking the three projects in this portfolio.

1. Viewing the full season as a window of opportunity

Project two and three both provide information regarding the pre-season phase of training in professional football. Project two shows that there is an association with strength training and the reduction in injury rates during the pre-season phase. Project three shows that only small improvements in isometric force are achieved during the PS phase, whereas greater improvements can be achieved longitudinally across the season. Traditionally the in-season has often been looked at as a maintenance phase for strength and power development. Information gathered from this portfolio may give an understanding of how S&C practitioners could view the in-season phase as an opportunity for positive adaptation in physical performance. As a result, the pre-season phase could focus on pushing for

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improvement of muscular strength for injury reduction, increased robustness, and to set the foundations for improving physical capacities during the in-season, rather than viewing this as the only opportunity for strength adaptation during the season. Realistically, the pre-season period is 5-7 weeks in duration. This is a relatively short period of time to expect large increases in physical performance and expect this adaptation to last for the following 10 months.

2. Implementing research in professional sport is challenging but results are achievable

Real world professional sport environments are complex, dynamic and ever changing and can result in difficulty implementing research into these contexts. However, this does not mean that efforts should not made to produce research, with high ecological validity, specific to the professional sport environment. In fact, understanding evidence-based research may help develop research questions and strategies applicable to enhanced sport performance.

There are obvious limitations to evidence-based research conducted in this portfolio, namely project two and three. For example, each project has a limited sample size (n = 20 and 18) or outcome rate (e.g. number of injuries in project two) that may limit the use of statistical methods. In addition, there is a multitude of variables that may affect the results seen, such as the concurrent training load or match involvement that was not accounted for in project three. However, these constraints will likely be the case for many practitioners' working in professional football, and as such my findings may be more useful than laboratory conditioned trails, or research obtained from untrained, non-sporting population.

What can be seen from the results in project two and three, is that research can be conducted in professional sport, and can show positive outcomes for injury reduction and improvements in force production characteristics.

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3. Prioritising performance and injury prevention is supported by my findings

Injury prevention exercise programmes are an inherent part of training in professional sports. Providing performance-enhancing benefits in addition to injury prevention may help adjust coaches and athletes' attitude towards implementation of injury prevention into daily routine. Practitioner opinions as seen in project one suggest that improving performance outweighs preventing injuries with their S&C programming. Project two shows that an S&C programme is associated with a reduced injury rate, and project three shows that strength performance can be increased across the season. Collectively, this supports the notion that strength training, when incorporated, has the potential to reduce injury rate and improve physical performance in professional football players.

4. There is a need to provide individual approaches and understand individual responses.

The requirement for individualization of training programmes is a common priority for practitioners. Project 1a illustrates that S&C sessions are often individually tailored, with practitioners' stating that players do the same compulsory exercises but have specific individual extras, and exercises are individual, based on a needs analysis of each player. Individualization of training may not mean every player has to have a completely different session, or even different exercises. Resistance (load), velocity of movement, intent to move quickly, volume, frequency are just a few ways to manipulate and create individualization in training programmes within a group environment, as suggested by some practitioners in project 1a; who state exercises are the same for all, but load and volume are individual. What

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may be more important is the understanding that players do respond differently to a given training stimulus (e.g., gym load) or to the overall concurrent training load (match, training and S&C) and therefore how we, as practitioners', can adapt our programming accordingly.

6.13 Practical implications of findings

Project one – the data enabled a greater understanding of S&C methods and practices in elite male football, and the challenges that are frequently faced. As a consequence of the two published articles (project one a and one b), S&C coaches and sports science practitioners' who work at all levels of professional football may use this information as a resource to understand, assesses, inform and improve their current and future practices. In addition, graduates or S&C coaches wanting to work in professional football may tailor their continued professional development to align with contemporary practices outlined. For example, understanding that GPS monitoring is used by 82% of practitioners on a daily basis, may suggest that students seek out opportunities to get hands on experience of using GPS before applying for internships or jobs. Furthermore, findings suggest that athlete feedback and building relationships are a key determinant of a successful S&C programme, which is in agreement with previous research (William & Kendall, 2007). Understanding these soft skills may help future and current coaches' practices.

Project two – the information provides detail of the S&C and training load practices during a pre-season calendar utilized in elite football, with an understanding of the factors that may influence injury rates. As a result of a strength training intervention, there was a reduction in total number, injury rate and total severity of non-contact, muscle and tendon injuries across a

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pre-season training period. Thus, it appears that there is still scope to conduct training interventions using traditional resistance training methods, with heavier loads that are targeting specific increases in strength (i.e. >85% 1RM) and some form of periodisation, overload and progression in football players to support the reduction in injury risk. Our analyses support the notion that the inclusion of strength training, and subsequent volume and frequency, is closely related to the prevention of non-contact muscle and tendon injuries. Subsequently, I believe the evidence provided in this project is sufficient to warrant a paradigm shift from the current dominance of multicomponent prevention programmes, whereby minimal or no load is incorporated, towards strength training programmes as the primary intervention to prevent sports injuries. Overall, this information may help enable S&C coaches working within football of a similar environments, to optimise injury prevention strategies, and has helped provide me with a greater belief in my practices at Cardiff City FC.

Project three – the information provides an in-depth description of the isometric force and RFD response to concurrent training across a different phases of a full football season.
The key application of the findings is that including strength training throughout the season can improve force production in many elite football players, contrary to the often reported decrement or need for maintenance. Therefore, it is deemed imperative for the practitioner to closely and regularly monitor response to concurrent training and match play to identify those who may not be positively responding. Manipulation and understanding of these athletes overall training load should then be assessed with the aim of producing a positive long-term adaptation. As such, it could be suggested that there is a need for individual approaches to programming strength training in elite footballers. In addition to project two, results suggest that targeting strength training during the pre-season and early in-season when frequency of

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S&C practices can be greater than during other phases, is important for the long-term adaptation of players force producing capabilities. Consideration of baseline force characteristics may allow for a more accurate description of neuromuscular response reflected in testing assessments. In particular, greater level of strength earlier in the season may help reduce some of the negative physical effects seen during the congested fixtures and chronic accumulated fatigue, such as performance decrement and increased risk of injury.

6.14 Impact of the portfolio on my own practice

On a personal note, information gained from project one has helped inform my own decision making in practice. Recently, a graded recommendation approach has been proposed to assist in practical decision making (Arden et al., 2019). This process involves: 1) reviewing and assessing research-based evidence: 2) interpreting the research-based evidence, and 3) combining the consensus from research with practice-based experience (including assessing current practice) and the feasibility of use in the practical setting. This is considered important because assessing current practice (both your own and the current practice of other practitioners around the world) is a key component of the decision making approach. The best research evidence may not be feasible in practice, with research still playing catch-up to current practices, and opinions from experienced practitioners' may help shape your decisions to a greater extent than those published in research.

With regard to my own personal practice, as a result of findings of project two and three specifically, I now incorporate a lot more strength training into our weekly programme. Previously, a lot of pre training preparation focused on mobility, foam rolling, and banded 'glute activation' exercises. Now I have tailored a periodised plan for pre-training strength,

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speed and power development exercises. I utilize an under-loading method for traditional strength lifts and incorporate isometric and RFD movements. Overall, the intention is to provide micro-dose exposures consistently across the season, especially when periods of fixture density do not allow for traditional lifting sessions for the majority of the playing squad. As a result, players can now receive 2-4 pre-training micro-doses of strength training per week, in addition to their weekly main "heavy" lower limb lift.

6.2 General discussion

The purpose of the following sections are to evaluate the outcomes of this portfolio and discuss what questions have emerged from the findings. Each chapter will evaluate a key finding and its application. The overall purpose of the portfolio was to gain a better understanding of S&C practices in elite football, and how scientific research can be extrapolated to the practical day-to-day environment of elite football. Therefore, the key concepts that have emerged are: 1) how "content is king, but context is god" in terms of application of data (6.21); 2) Can we create an unbreakable athlete? (6.22); and 4) the future of S&C (6.23). In addition, this chapter will conclude with suggestions for future research (6.3) and how this portfolio meets the requirement for level 8 qualification (6.4).

6.21 Evidence based practice: *"Content is King, but context is God"*

The purpose of this chapter is to explore the need for applied research; the difficulty with application of research in professional sport and to highlight how the projects in this portfolio address this issue. Research conducted on professional team sports is largely observational. Challenges exist for the practitioner in implementing peer-reviewed research into the applied

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setting. Results highlighted in project one, show that professional practice does not always follow recommended research advice, as too much research is clinically based and not always applicable to the real-world situation, which can be supported by previous research (Reade et al., 2008). In addition it was suggested that there is not enough research published using the level of athletes we work with, there is not currently enough practical day-to-day research being published, "*it's not always feasible to include these evidence based preventive measures into our training programme*" (participant 11), "*we include a better programme than those recommended in the literature*" (participant 7), and "*literature isn't always correct, despite being statistically significant".* In support of some of these observations, it has recently been suggested that practitioners' and researchers may benefit in sourcing information, producing research and disseminating findings that better align with practitioners' needs (Fullagar et al., 2019).

An important goal for most athlete-centered research is for it to be translated into practice, where it is used to inform the development of improved athlete preparation and / or performances. The results of this process is commonly termed evidence based practice (EBP). During the last decade, the concept of EBP in high-performance sport has gained great interest among sporting practitioners' and researchers. While there is no widely adopted definition of EBP in sport, we can adapt definitions from medicine into a sporting context. In medicine, EBP can be described as "the integration of best research evidence with clinical expertise and patient values" (Sackett et al., 2000 page 71). By modifying this definition and replacing the terms clinician and patient with coach and athlete, we can develop a working definition of EBP in sport. Accordingly, EBP in sport can be described as the integration of coaching expertise, athlete values, and the best relevant research evidence into the decision making process for day-to-day service delivery to athletes (see figure 6.1).

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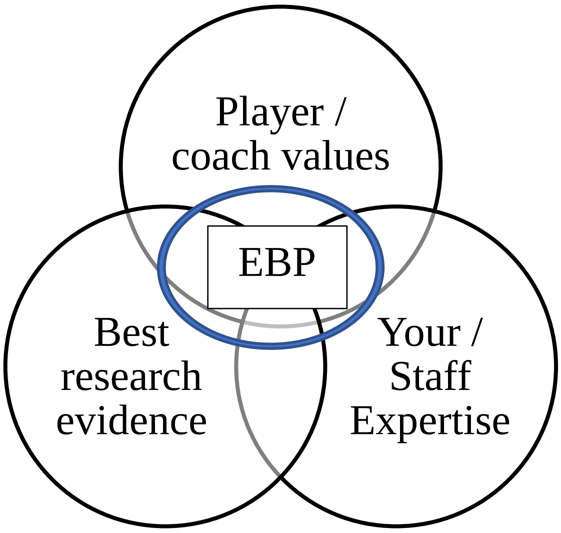

Figure 6.1. Representation of the definition of evidence based practice in sport. Adaptation of (Sackett et al., 2000) Evidence-based medicine. Churchill Livingstone

The use of an integrated EBP in elite sport may improve training and performance, reduce training errors such as inappropriate training, reduce injury rates (as proposed in project 2), improve physical characteristics, and challenge belief-based views with evidence (both proposed in project 3). Translating knowledge to practice is a critical final step of EBP to positively influence player well-being, and team success. While results from project one suggest that practitioners' place value on published research, they often find it difficult to implement recommended best-practice. Real world professional sport environments are complex, dynamic and ever changing and can result in difficulty implementing research into these contexts. This can be a consequence of players (who act as subjects) getting injured or transferring away from the club, changes in fixtures, changes in training schedule, and changes in staff or management. In addition, a common obstacle for researchers working in sport is the difficulty of conducting randomised controlled trials in elite athletes (Altman, 1996; Fanchini et al., 2020). Unfortunately, a RCT is uniquely difficult to perform in athletic populations. These issues may explain why there are relatively few RCT in elite sport. The methodology used in project two goes someway to addressing this issue. Although not a

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RCT, there is a natural control vs. intervention group, that occurred not as a result of scientific intervention for the purposes of this portfolio, but one that occurred naturally within Cardiff City FC training plan (see project 2 for further description). In addition, results from project two and three provide some evidence based approaches to S&C application in football.

The impact of this portfolio to the concept of applied practice is demonstrated throughout the three projects. As previously discussed, attempting to apply peer-reviewed literature into professional sport is a challenge faced and contested by current practitioners. In addition to many of these challenges facing practitioners' in applying non-specific research, much of the evidence available contributing to S&C practitioner knowledge is focused on scientific components of programme design, assessment and / or technique. Operating as a practitioner requires attributes other than just traditional scientific knowledge. The art of coaching, the application of the science, and the ability to deliver sessions in a variety of situations is often attribute that is often under-reported. Therefore, a key consideration for understanding practical applied research is to dig deeper into "what makes a good, or successful S&C coach". Consequently, to further understand the relationship between research driven science and the application of practice, researchers should explore how S&C practitioners apply scientific knowledge and personal professional knowledge into practice.

The impact of my portfolio does demonstrate an ability to apply scientific knowledge (e.g. strength training has proven benefits on injury rate) and personal professional knowledge (e.g. how I had to fit our S&C sessions into a pre-season period dictated by the manager and his high training load) into practice.

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In conclusion, the gold standard approach to optimising high-performance outcome such as injury prevention in professional team sports is considered through the adoption of an EBP approach (Coutts, 2017). An EBP approach involves a combination of high-quality research (i.e. scientific evidence) and current best practice (i.e. practitioner experience). In support of this, Bishop, (2008) suggested that where possible, practitioners' should preferentially adopt strategies to align evidence-based interventions with the demands of professional settings. Additionally, to fully understand the overall application of research into practice, practitioners should aim to publish research on how they combine the science and the actual "doing" of S&C in football to create their S&C programme.

In addition to trying to develop EBP to help practitioners', there are other conclusions regarding data reporting that have arisen from this portfolio. For example, the use of rigorous statistical methods such as mixed linear modelling are very useful for understanding the data when applied in an academic setting, such as a PhD or published research. However, there can be difficulties utilizing statistical measures when sample sizes are low, number of observations are inconsistent or the number of reported measures (e.g., number of injuries as seen in project 2) are also low. The balance between academic reporting and the real-world situation have previously been discussed by Akenhead & Nassis, (2016). They comment that given the potential diversity of a football squad (e.g., variation in non-modifiable risk factors such as age, training history, injury history), and the many degrees of freedom associated with resultant training and competition load (e.g., playing time, positional role, opposition), training load and individual responses can vary markedly between players (as seen in results of project three). Practitioners should therefore be interested in the change within individual players. The magnitude of change of any variable must be considered in relation to its intra-player reliability (Hopkins, 2000; Hopkins et al., 2009). A method advocated by Hopkins et

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al., (2009) expresses change relative to intra-player reliability (CV%) or that of the smallest worthwhile change (SWC). SWC is a reference value selected by a practitioner or researcher to indicate a value beyond which a change in true score is likely to be meaningful in practice. What actually matters to practitioners' is whether the training-related changes could be important (i.e., whether their magnitude is actually greater than the smallest practical or meaningful effect; Batterham and Hopkins, 2006; Hopkins et al., 2009). However, from examination of the current data and published literature, this method does not seem to be universally adopted in high-level football or applied football research. The seemingly low use of such analyses in the club setting may be related to a lack of awareness of the statistical methods, insufficient experience in implementing the method, or perhaps a lack of time and human resources (Akenhead & Nassis, 2016). Clubs and practitioners' seeking to enhance the meaning and usefulness of their data may wish to familiarize themselves with these methods or seek outside expertise to assist with this process. However, speaking from experience, this type of data analysis rarely happens in professional sport, unless the research is designed for wider publication or the practitioner has an academic interest. There are few, if any, players or managers who would value or understand the outputs from these statistical tests. It is far more likely reporting % change or difference pre and post in a selected unit / measure (e.g., cm for jump height, or where players sit within the group or against players of the same position) will be understood by players and managers. In addition, as suggested by Gabbett et al. (2019) "any statistical approach must also consider the real world demands of sport; practitioners must collect, interpret and act on data under great time pressure" (pp. 395).

In conclusion, as each situation is often challenged by its own uniqueness, not all research can be or should be applied to your team or environment. Using an evidence-based approach, via a combination of the applied literature, yours and your staff's expertise, and the values of the player, coach and team would most likely provide the greatest benefit. In my opinion,

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appropriately collected research on your team should also be conducted and applied, even if it's not designed to be published.

6.22 Can we create an unbreakable athlete?

The holy grail of improving performance and reducing injury risk

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A frequent concern for all S&C and medical practitioners' working in sport is trying to mitigate the risk of injury. However, it could be asked "what is injury prevention, and is it possible?". As defined by Merriam-Webster, to prevent, is "to keep from happening". While this is a noble goal in musculoskeletal injury, the nature of sport and injury leads practitioners' to attempt to find practical ways to manage and reduce risk. General prevention and 'load management' methods often rely on the removal of exposure, which is not advantageous to sporting population (Eirale et al., 2013; Drew et al., 2017). After all, avoiding loss of participation is the goal of prevention. Risk reduction strategies are likely to be a more realistic strategy for the common goal (Shrier et al., 2015). If we are trying to create an unbreakable, high performing athlete, many factors need to be controlled (Gabbett et al., 2019). However, with the increasing physical demands placed on an elite footballer, is this an unreachable dream? The risk of injury is heightened by many modifiable and non-modifiable factors (see paper 2 for more details) such as age, previous injury, training load and strength.

If, as practitioners' we try to control or remove the risk of all these factors, we are in danger of not pushing the players to reach their full physical capabilities. After all, the role of an S&C coach is to help athletes achieve high levels of physical performance.

In addition to managing the risk of injuries, S&C practitioners should also focus on improving physical capabilities. The holy grail paradox between prevention and performance

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is often difficult to achieve in the professional sporting environment with the demands of congested fixture schedules, increases game intensity, increased max speed and high-speed running exposure (Ekstrand et al., 2020) making it difficult to include recommended practices (Beere et al., 2020; Project 1a). Therefore, large increases in physical performance capabilities across a season are scarcely reported (see project three for further discussion).

There is much debate about the feasibility of predicting injury occurrence (Bahr, 2016). Whilst it seems near impossible to predict all injuries occurring, it may be sensible to attempt to mitigate / reduce the risk by modifying certain variables that have a high correlation with injury risk. One such variable is strength. While many previous studies have implemented injury prevention plans in professional football that focus on balance, core, low load activation exercises (Owen et al., 2013) such as glute band movements, it would seem logical to focus attention on improving athlete strength with traditional strength training methods (supported by research; see project 2). As well as potentially reducing the risk of injury occurrence, there are also numerous performance benefits to increasing athletic strength and the ability to produce that strength in sport specific situations, such as RFD.

While project two and three utilised players and data from different seasons, (project two 2017-2018, and 2018 - 2019; project three 2019-2020), viewing results as a whole would suggest that strength training has the potential to reduce injury rate and severity, as well as improve measurements of force production (peak force and RFD) in professional footballers. Therefore, S&C practitioners in professional football have the opportunity to use their understanding of sports science and coaching to achieve the primary objectives of reducing injuries and improving physical and sports performance (project one).

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6.23 Future of strength and conditioning in football

One of the many unique and interesting aspects of this investigation into S&C practices in football (project one) is the question: what is the future of strength and conditioning in professional football? Practitioner responses from project one (Part C) include: *"soon be a split between S&C and sports science practices*" (participant 16), "*S&C will take a big role in rehabilitation"* (participant 16)*, "the increased demands of the game and athletes will improve buy-in" (*participant 9)*, "more data driven"* (participant 18)*, "more integrated with coaching staff"* (participant 27), *"a need to quantify gym performance in the way GPS quantifies pitch work"* (participant 1), *"more adherence from players who come through the academy pathway"* (participant 22)*, "with players becoming fitter, faster, stronger, the role of the S&C coach will become more vital"*(participant 33) *"need to understand that we are part of football performance, not gym performance"* (participant 18), and *"Strength coaches need to understand more than just the gym and getting stronger being the only answer"* participant 14). Although not specifically asked, many coaches gave answers relating to salaries and roles within the industry. Selected answers include "*hope that S&C coaches get the same recognition in terms of salary as other medical staff"* (participant 14), *"clubs will recruit staff for less money as they know there is a high demand for these jobs"* (participant 29), *"best practitioners' are leaving the game due to undervalued salaries"* (participant 49), and *"there isn't the same career support pathways as there is with technical coaching"* (participant 31). Although undoubtably heavily biased, in support of the idea of importance in S&C practices, project one shows that 86% of practitioners' believe that S&C are very important or important to football performance. What may be of interest in future research is to survey the opinions of players and other staff members on the importance of S&C practices.

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An additional unique and interesting outcome of the research is the always controversial conversation on internships. Results in this portfolio suggest that an internship is almost universally required to work as a sports scientist or S&C in professional football. This is in contrast to other disciplines such as physiotherapy and soft tissue therapists. Despite the apparent growing importance placed on S&C in football, could S&C be considered a graduate entry profession within many professional football clubs? In my experience, having completed internships at two different football clubs and now seeing the influx of S&C students applying for internship placements, could we ask: is the S&C market already becoming saturated, and do clubs know they can exploit this with poorly or unpaid staff, whilst expecting high levels of both experience in the field and education? You only have to read a job description to see that even internships often require a master's degree, a professional accreditation, such as the UKSCA, and experience working with professional athletes. Responses from other practitioners seem to suggest this may be a worrying and all too common requirement within professional football.

Project one showed that 90% of practitioners' value building trust and effective relationships with players to be the most valuable method for creating a positive attitude towards S&C. Additionally, 80% of coaches reported effective communication with athletes as the second most valuable method. It appears there is significant value given to practical experience and communication skills to be a successful S&C practitioner. Taken together, this advice and the findings of project one could be useful for young practitioners', who may wish to seek early internships and experience in applied settings, alongside their formal education. In addition, there appears an increased need for education for students on how to communicate with other coaches and athletes.

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6.3 Future research directions

Additional research in this area will only help further our understanding of how best to develop S&C coaches and practices within elite football.

Project one: Interestingly, coaches have shown that communication and relationship building skills are considered more important at creating player programme buy-in than anything else, including exercise selection. It would therefore be of interest to coaches and researchers to find ways to develop these skills to enhance the success of S&C practices to professional football players. Although undoubtably heavily biased, in support of the idea of importance in S&C practices, project one shows that 86% of practitioners believe that S&C are very important or important to football performance. What may be of interest in future research is to survey the opinions of players and other staff members on the importance of S&C practices.

Project two: While showing that strength training can help reduce injury rate is of significance to the practitioner, to create a greater level of buy-in from management or the club as a whole, practitioners' could also report the findings in relation to the team performance (points or change in league position) or financial cost of an injury to the club. Additionally, it may be of further interest to include performance test outcomes such as CMJ, speed, or strength scores to see if the inclusion of strength training not only reduces the risk or injury but also increases the athletic qualities of footballers during this period. Furthermore, it would be beneficial to see the effects of strength training on training or match related performance outcomes such as amount of sprint or high intensity distance covered. It is probable that not all load is equal, and that some stimuli (e.g., exposure to high-speed or

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sprint running) are more important than others from an injury perspective. Therefore, understanding how training load variables such as amount of HSR distance or sprint frequency may be enhanced by increases in strength training volume or athlete strength would also be of interest for the practitioner. For example, does an increased frequency of S&C exposure or stronger players, cover greater HSR distances or perform a greater number of sprints during match play.

Project three : Future work could examine other factors that may affect changes in physiological characteristics over the course of the a whole season. Further quantification of total work performed by players in both match and training may provide greater insights into the factors which effect change in force and RFD qualities over the course of a season. The widespread use of GPS data within professional football represents a means of quantifying both distances covered and the frequency of high intensity efforts. Examining such data within the context of changes in force and RFD could be of interest. It could be of interest to many practitioners to provide detailed analysis of the type of periodisation followed across a season to assist the practitioner in optimising their delivery and training strategies.
Finally, future research should aim to establish the association between force outputs and training or competition load data, to better understand the interaction between force and in-game football demands.

Overall, future research should continue to encourage ecological valid studies to help enhance the relationship between academia, research and practice. Practitioners' working within professional football are blessed with a wealth of evidence-based knowledge and access to elite performers. Academics will often have a greater understanding of research methods and statistical analysis that, when merged together should help produce high quality, ecological

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valid, useful practical research that can help enhance the understanding and delivery of strength and conditioning practices.

6.4 Novel Contribution in Line with Level 8 qualification

In order to demonstrate how this portfolio offers an "*original and independent contribution to knowledge that is at least equivalent to that normally demonstrated by the submission of a thesis*", evidence is presented against the criteria for the award detailed in the USW PhD Portfolio Guidelines.

A doctoral degree (Doctor of Philosophy, PhD) shall be awarded to a candidate who has:

1. Demonstrated the creation and interpretation of new knowledge.

Detailed in the Key findings and Contribution to the field sections in chapters 3, 4 and 5, and the *Evaluation of aims and objectives* in chapter 6. This portfolio consists of three projects that collectively form a rigorous body of evidence that has explored S&C practices in elite male football.
Interpreting the data from project one in a way that allowed the information to be appropriately disseminated and utilised to directly impact on professional practice is a clear indication of the integrated nature and quality of the research presented in this portfolio.

2. Conducted original research or other advanced scholarships

Three original manuscripts have been produced as a result of projects one, two and three of this portfolio.

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3. Conducted research of a quality to satisfy peer review

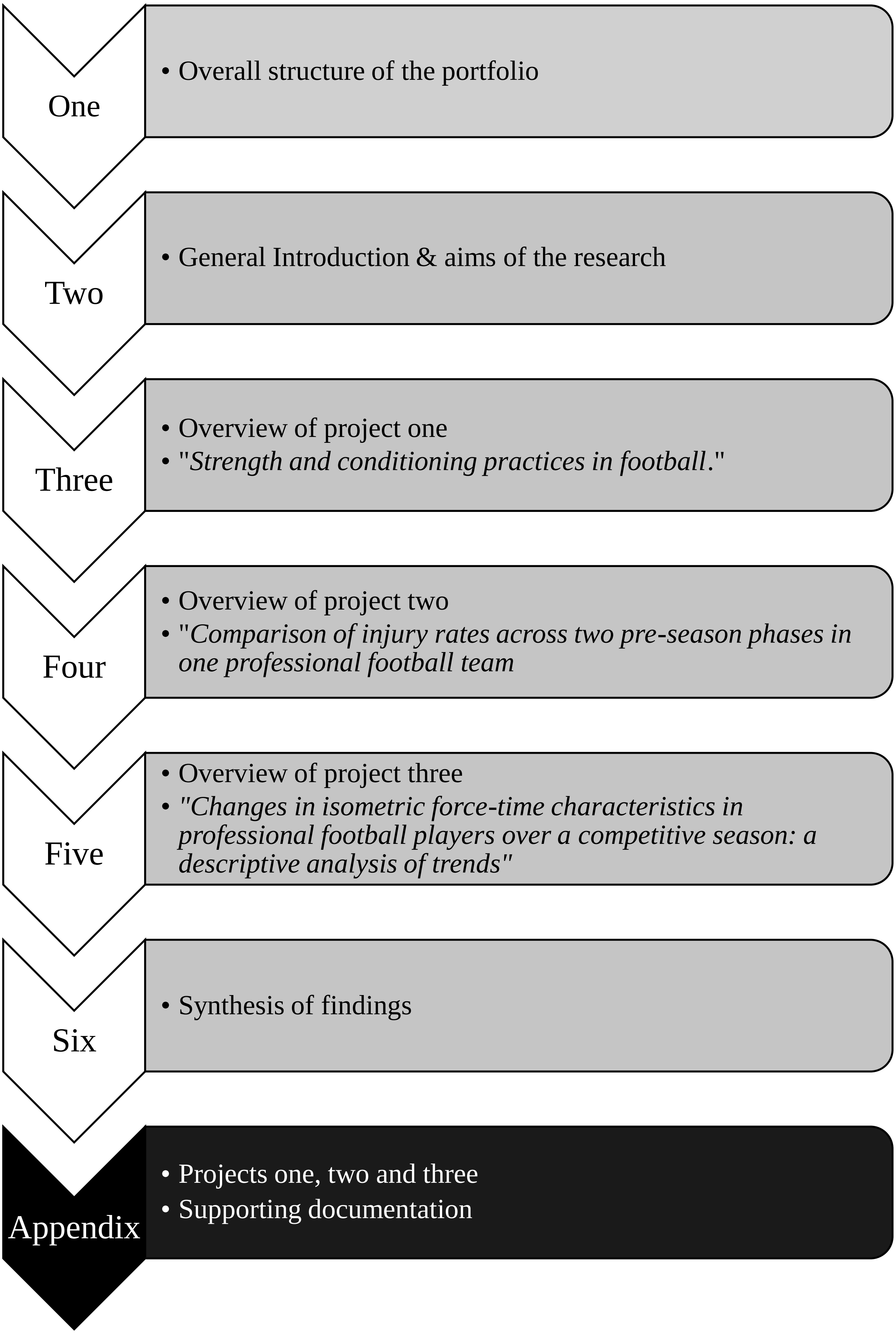
The two manuscripts in project one have been fully published in a peer-reviewed journal. The manuscript presented in project three is currently under peer-review (please see pages 6 for a list of publications associated with this portfolio).

4. Extended the forefront of the discipline

A number of unique contributions to the literature and to the wider field have been made. Specifically, this portfolio showed that there is scope for well conducted research to be permitted in professional sporting environments that can enhance knowledge in the field of Strength and Conditioning in elite football. The portfolio, as a result of the publication of project one, has for the first time provided a body of evidence that practitioners can use to review current practices and also provide new ideas for diversifying/modifying future practices. In addition, graduates or S&C coaches wanting to work in professional football may tailor their continued professional development to align with contemporary practices outlined. Furthermore, results from project three have shown that force production characteristics can be enhanced throughout a competitive football season, which contradicts the much publicised idea that, at best, strength can only be maintained throughout the season.

5. Merited publication

The two manuscripts in project one have been fully published in a peer-reviewed journal. Part of the manuscript presented in project three is currently under peer-review (please see page 6 for a list of publications associated with this portfolio).


One
• Overall structure of the portfolio
Two
• General Introduction & aims of the research
Three
• Overview of project one
• "Strength and conditioning practices in football."
Four
• Overview of project two
• "Comparison of injury rates across two pre-season phases in one professional football team
Five
• Overview of project three
• "Changes in isometric force-time characteristics in professional football players over a competitive season: a descriptive analysis of trends"
Six
• Synthesis of findings
Appendix
• Projects one, two and three
• Supporting documentation

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APPENDIX

PORTFOLIO OF EVIDENCE

Project one: Strength and Conditioning provision and practices in elite male football

Project two: Comparison of injury rates across two pre-season phases in one professional football team

Project three: Changes in isometric force-time characteristics in professional football players over a competitive season: *a descriptive analysis of trends*

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PROJECT ONE

STRENGTH AND CONDITIONING PROVISION AND PRACTICES IN ELITE MALE FOOTBALL

This project is subdivided into three separate projects (part A, B and C). Each explore the results from the same questionnaire on the same practitioners'

Findings from this project were published as two separate papers in a peer-reviewed journal

1a) Beere, M, Jeffreys, I and Lewis, N. Strength and Conditioning provision and practices in elite male football. *Professional Strength and Conditioning journal* 27-33, 2020.

1b) Beere, M & Jeffreys, I. Physical testing and monitoring practices in elite male football. *Professional Strength and Conditioning journal* 27-33, 2021

In addition, Part 1C, completes project one and presents the findings that were not published.

The content of the two papers is presented in the format required for publication

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Strength and conditioning provision and practices in elite male football

By **Mike Beere**[1], **Ian Jeffreys**[2] and **Nicki Lewis**[2]
Cardiff City Football Club[1] and University of South Wales, Cardiff[2]

INTRODUCTION

There is limited published research on strength and conditioning (S&C) practices in elite football. Information regarding programme design and factors that impact programming would provide valuable information to applied practitioners and researchers investigating the influence of performance interventions strategies. The aim of this study was to detail the current practices of S&C coaches working in senior male football. A questionnaire was developed comprising three main sections: personnel details and staff structure; strength and power development; and current issues and barriers to practice. A total of 51 (51 men; age 32.45 ± 7.27 years) out of 74 (68.9%) coaches responded to the questionnaire, all of whom had been working in senior male football for 9.61 ± 5.65 years. All respondents believed that strength training benefits football performance and reported that their athletes regularly performed strength training. The trap bar deadlift was rated the most frequently prescribed exercise. One hundred percent of respondents reported prescribing plyometric training, and 43 (84%) indicated that periodisation strategies were used. Time availability was considered the biggest factor impacting programme delivery. Building trust, relationships and communication were seen as the biggest determinants of successful S&C practice. This survey represents new data regarding S&C practices in elite male football and serves as a review of applied information.

Introduction

Professional football is the world's most popular sport: the Federation of the International Football Association (FIFA) estimates that more than 270 million people are actively involved in the sport worldwide.[86] In recent years there has been a remarkable expansion in, and acceptance of, sport science (SS) and strength and conditioning (S&C) practices within football.[54] Strength and conditioning is a discipline that is recognized as a valid area of scientific and professional practice, with S&C practitioners' increasingly becoming key members of the multidisciplinary coaching team.[54] Given the accepted importance of physical conditioning today, many teams hire S&C coaches to help prepare athletes for performance and to avoid injury.[21,38]

Football is a highly challenging sport to support. In addition to the necessary technical and tactical skills, football players must develop and maintain a high level of athleticism to be successful and can require different – and in some cases – contrasting physical qualities for successful performance.

The development of a literature base quantifying the physical demands of elite football has allowed practitioners to gain a greater understanding of the physiology of football and thus potentially programme more effectively for their athletes.[57] The required increase in the physical demand of successful performance is demonstrated with the year-on-year increase in match play intensity in English Premier League matches.[9] Here, high levels of strength, power and endurance are required to sustain the increased distance covered, number of sprints and high speed running actions performed.[7] However, despite the increased input from S&C and SS practitioners, and the potential to enhance practice, there remains a challenge in fully integrating this work into the practices of football at multiple levels. This situation is often exacerbated by a lack of understanding of the roles that S&C coaches play and the practices utilised within the game.

Over the past decade there has been a surge in football-related information in the field. This has involved the application of multiple modalities, including monitoring of on-field training practices,[57] injury prevention,[53,54,60] fatigue monitoring,[83] return to play criteria,[80,20] and training load.[49] However, although these areas have received plenty of review, there appears to be a relative dearth of research exploring the function of traditional S&C practices, and even less concerning the practices, strategies and periodisation used by S&C professionals in elite male football.

S&C practices have been examined in numerous other sports including basketball,[73] ice hockey,[24] American football,[22] rugby union,[40] rowing,[34] baseball[23] and cricket.[64] However, there are very limited available data on how S&C professionals operate in elite football. Research in football has typically focused on injury prevention methods in international Premier League clubs,[53] during international competition,[54] and during the return to play/perform process.[20] Unfortunately, there are currently no data regarding specific details on methods of application, such as session distribution, session frequency and periodisation strategies; staff structure; methodologies utilised, programming rationales, and session compliance. Similarly, there is no clear understanding of the logistical challenges facing S&C coaches, such as the impact of match schedules on programming, the impact of the coaching team and how these challenges at elite professional level impact the implementation strategy of the S&C coach. In addition, information regarding how practitioners overcome the challenges faced in day-to-day delivery of S&C programmes has never been reported. Yet without an understanding of context, the challenges of application can never be fully elucidated.

Therefore, the purpose of this survey was to examine a variety of S&C practices and to determine the common and the unique practices employed in elite male football. Information obtained from this research will allow coaches access to a serviceable source of the collective ideas of others that they can then use to compare with their own provision, and potentially incorporate into, their own practices. This information may also help inform training programme design for future studies seeking to examine the influence of S&C interventions in elite football players.

Materials and methods

EXPERIMENTAL APPROACH TO THE PROBLEM

This study utilised a quantitative research design in the form of an online survey to examine the current practices and perceptions of S&C coaches in senior male football clubs in the UK and USA. The survey, titled 'Strength and Conditioning Questionnaire', was adapted from that commonly used in other sports by Ebben and Blackard.[22] The questionnaire was adapted to be specific to football, to the demands of this research and to test the hypothesis that football S&C coaches follow contemporary and scientifically-based principles of strength and conditioning practices. It was hoped that coaches would be willing to share their ideas, practices and perceptions through this survey.

SURVEY

The questionnaire was pilot tested on a group of five S&C coaches, academics and researchers in order to determine the reliability and validity of the questions. Once feedback was received, certain questions were modified. This included changing the order of the questions, so that the logical order would be improved, changing some qualitative questions to quantitative queries and rewording questions to make them clearer. After this, the survey was reassessed by a supervisory panel before being sent to the coaches.

The survey consisted of three main sections: personnel details and staff structure; strength and power development; and

Table 1. Competition standard of respondents' clubs

PREMIER LEAGUE	CHAMPIONSHIP	LEAGUE ONE	LEAGUE TWO	NATIONAL LEAGUE PREMIERSHIP	SCOTTISH SOCCER	MAJOR LEAGUE
9	17	8	7	2	3	6

current issues and barriers to practice. The survey contained 48 questions (3 open and 45 closed) relating to the objectives and methods of S&C practices.

The online survey was distributed to S&C coaches, sports scientists and medical professionals working in professional senior male football teams in the UK and America via the website sogosurvey.com.

DATA COLLECTION

All subjects were informed of the purposes of the investigation before participating in the study. An initial email or message via social media platforms describing the study was sent to the S&C coaches at the selected football clubs. This message included a description of the broader study, and an explanation of what the survey would entail. Only those who responded to assist in the research were then contacted by an email containing an electronic link to access the survey.

The coaches were given 30 days from the time of receiving the email to complete the survey. If no responses were received after 30 days, a reminder was sent for a further 30 days. After 60 days, the questionnaires that were completed were collated for statistical analyses. All data were collected between July and August 2019, and referenced the 2018-19 football season.

STATISTICAL ANALYSIS

All data were collected using an online questionnaire (sogosurvey.com, VA, USA). The survey consisted of a combination of fixed-response and open-ended questions. Data analysis procedures were descriptive in nature with frequency counts and percentages calculated. In addition, some of the questions were scored to produce rank scores, with the frequency count of each response reported, as well as a 5-point Likert Scale set as 1 (not at all) to 5 (very important).

RESULTS

PERSONAL DETAILS

Fifty-one (51 men; age 32.45 ± 7.27 years) of 74 (68.9%) coaches responded to the questionnaire. The respondents consisted of three head S&C coaches, twelve heads of sports science, six heads of performance, eight heads of fitness and one head of medical. A further four senior S&C coaches, one senior sports scientist, three first team S&C coaches, five first team sport scientists, one first team physiotherapist, three first team rehab specialists and one assistant S&C coach also responded. Two responders were highlighted as 'other', but no further information was given.

Out of the 51 responders, 45 (88.2%) practitioners were based in the UK, and 6 (11.8%) in the USA. Information on the level of the participants' clubs is presented in Table 1. On average, the participants had been working in professional football for 9.61 ± 5.65 years, and had worked in their current role for 2.97 ± 2.79 years.

STAFF STRUCTURE

A total of 452 staff worked in the 51 clubs that responded. The greatest number of staff were physiotherapists (N=123). Sport scientists (n=69), soft tissue therapists (n=66), sports doctors (N=52), and S&C coaches (n=48) were also reported as support staff. There were 61 interns, and 33 classed as 'other', such as nutritionists.

Subjects were asked how many support staff had previously completed an internship placement, at the current club or previous club. A total of 134 staff had previously completed an internship in the 51 clubs that responded. The greatest number of internships had been carried out by sport scientists (n=48, 36%). Strength and conditioning coaches (n=36, 27%), physiotherapists and soft tissue therapists (both N=23, 17%) were also reported as staff to have completed an internship. Two (1%) sports doctors completed an internship placement.

When analysed as a percentage of those currently in a job, 36 out of the 48 (75%) who were now S&C coaches had completed an internship placement; 48 out of the 69 (70%) who were now sport scientists had done so; 35% of soft tissue therapists and 19% of physiotherapists. In total, 29% of staff who currently work in football had previously completed an internship placement.

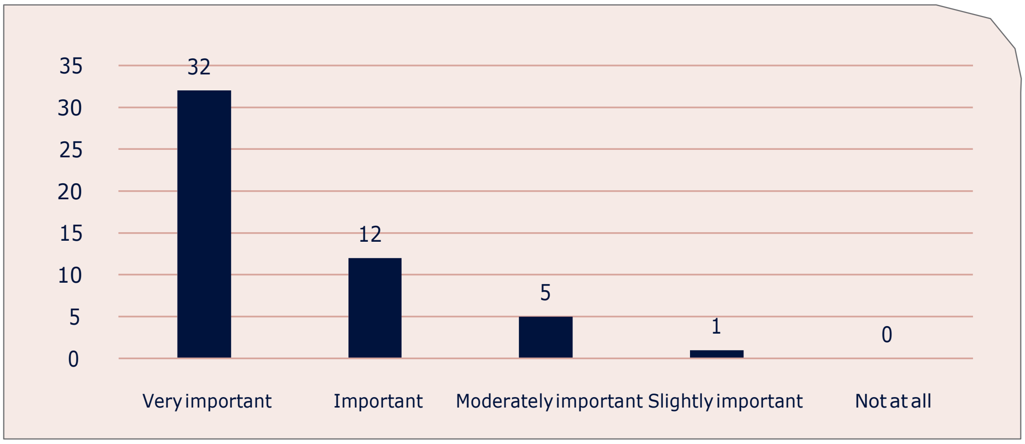


Figure 1. Perceived benefits of strength and conditioning practices on soccer performance

FORMAL EDUCATION

Fifty-two percent of total staff had an undergraduate degree in strength and conditioning, sports science or related medical subject; 31% held a master's degree in a related field; 4% held a PhD. In addition, 11% and 3% of total staff were currently studying a master's degree or a PhD respectively.

CERTIFICATION

A total of 112 staff members held an S&C related certification. The most commonly held professional certifications were the United Kingdom Strength and Conditioning Association (UKSCA) ASCC Accreditation, and also the National Strength and Conditioning Association (NSCA) CSCS certification (n = 37, 33%, and n=36, 32% respectively). Twenty-two (20%) staff held 'other S&C' certifications, and 17 (15%) participants were accredited with the British Association of Sport and Exercise Sciences (BASES). Forty members of staff were certified with a football-specific coaching certification. The most commonly held coaching certification was UEFA B licence (n = 29, 73%), with 10 (25%) holding a UEFA A and 1 (3%) with a UEFA Pro Licence.

STRENGTH AND POWER DEVELOPMENT

The initial question in the section asked if practitioners believed that S&C practices have an important benefit to improving football performance. Answers were ranked on a Likert scale of 1 – 5, with 1 = not at all, and 5 = very important. Fifty out of the 51 responders answered this question. Results on the perceived benefits of S&C on football performance are presented in Figure 1.

All 51 coaches stated that lower limb strength and conditioning was incorporated into their programmes. The top five reasons for including S&C are presented in Table 2, with answers weighted by rank score.

Forty-five (88%) out of the 51 respondents said that S&C sessions were compulsory for all players. Six coaches said that S&C sessions were not compulsory. An additional comment was: 'no punishment for not completing so can't describe as compulsory, but sessions are encouraged by management'. When asked to detail the percentage of players who regularly completed lower limb strength sessions, the most selected response was 91-100% (n=39, 76%). Six (11.7%) coaches responded 81-90%, and five (9.8%) said 71-80%. Only one coach responded 51-60%.

Coaches were asked to select what best described the S&C sessions provided; they were given the choice of more than one answer, with a total of 113 answers selected by the 51 coaches. The most common description (53%, N=27) was: 'players do the same compulsory exercises, but have specific individual extras'. Forty-nine percent (N=25)

Table 2. The top five reasons for including lower limb strength and conditioning practices

REASONS FOR INCLUDING S&C	RANK 1	2	3	WEIGHTED RANK (SCORE)
Help the players develop physical qualities needed	19	15	7	1 (94)
Make the players more robust	13	6	11	2 (62)
Stronger players are more resilient	4	11	8	3 (42)
Helps improve our injury rates	4	6	4	4 (37)
Enhance fundamental movement skills	5	4	6	5 (29)

stated that 'our S&C programmes prioritise performance enhancement strategies', and 47%, (N=24) that 'exercises are individual, based on a needs analysis of each player'. Thirty-three percent (n=17) stated that the programmes: 'prioritise injury prevention or reduction strategies'. Twenty-one percent (n=11) of coaches stated that: 'exercises are the same for all, but load and volume are individual' and 15.5% (n=8) stated that: 'the majority of the playing squad perform the same exercise'.

The final question in this sub-section asked practitioners about the typical duration of an in-season S&C session. Figure 2 presents the responses from the coaches.

STRENGTH AND POWER DEVELOPMENT: FREQUENCY OF SESSION

This sub-section asked how many, and on what days of the week, strength and conditioning sessions were performed during the in-season in relation to the next match day (MD). Figures 3 and 4 highlight the responses from coaches with regards to provision during a two-game week (eg, Saturday and Saturday); and a three-game week (eg, Saturday, mid-week and Saturday) respectively, and Figure 5 highlights when sessions were performed in relation to the next match day (MD).

During a three-game week, 16 (31%) coaches reported that all players completed at least one S&C session, 14 (27%) reported that only non-starting players completed a session, 15 (29%) reported that sessions were set on an individual basis, and 8 (16%) reported that no players completed any session. Reasons reported as to why no players completed an S&C session included: 'lack of time between matches doesn't allow full recovery', 'management want players to rest or have days off', 'a greater emphasis is placed on recovery strategies', 'not deemed appropriate', and 'no gym-based work, but extended power-based activation is performed on the pitch'.

The final question in this sub-section asked how external load (resistance) was determined during an S&C session. Practitioners could select more than one answer for this question. Thirty (58%) coaches responded that it was 'athlete-led'; 28 (55%) stated it was 'based on periodisation or phase of training'; 25 (49%) 'coach's subjective assessment'; and nine (17%) responded that load was determined by 'measures of velocity with the use of technology' and 'rep max or strength testing'. No-one suggested that load was similar for all players.

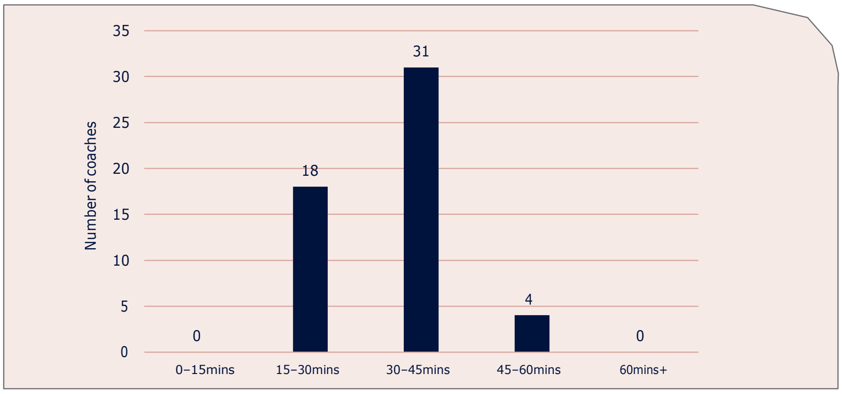


Figure 2. Average length of soccer strength and conditioning coaches' in-season S&C session

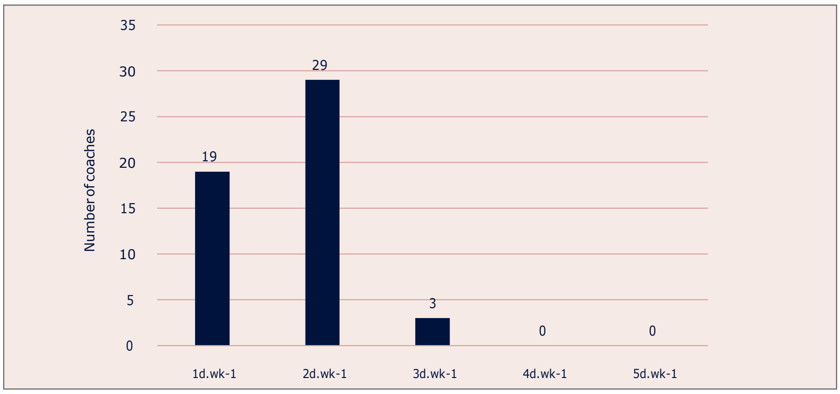


Figure 3. The number of strength and conditioning sessions provided in-season during a two-game week

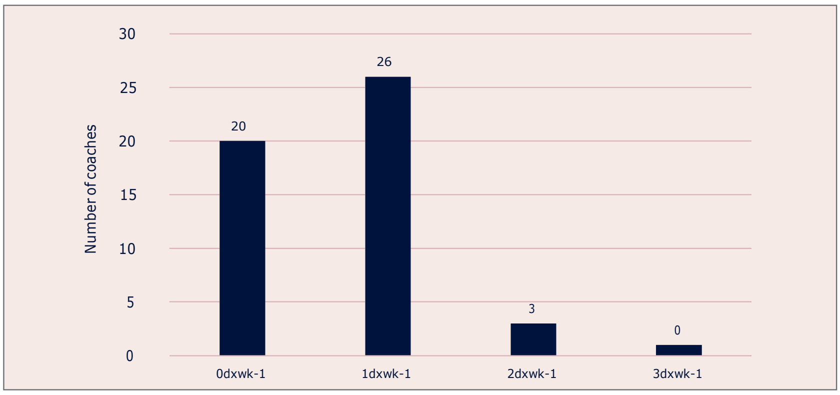


Figure 4. The number of strength and conditioning sessions provided in-season during a three-game week

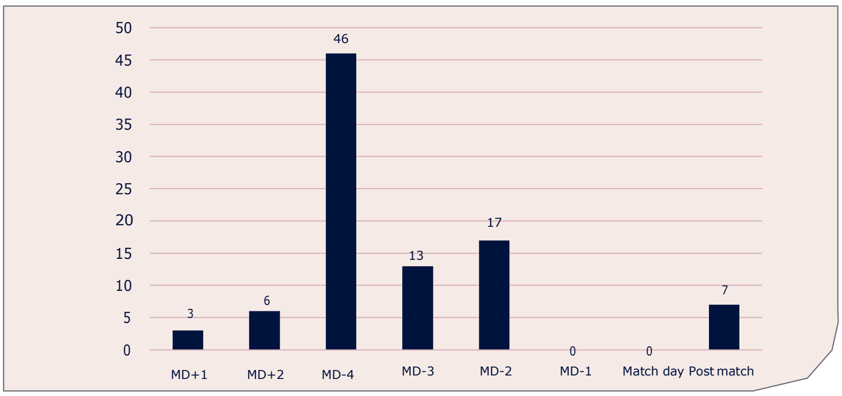


Figure 5. Days of the week strength and conditioning sessions were performed in relation to the next match day (MD)

STRENGTH AND POWER DEVELOPMENT: EXERCISE SELECTION

The next sub-section asked which exercise modalities were most commonly used in S&C practices. Answers were weighted by rank score. Thirty-seven (72.5%) coaches ranked using free weight (barbell, dumbbell or kettlebell) resistance at number one. Plyometric exercises were ranked second with Nordic hamstring curls third. Derivatives of Olympic weightlifting movements and isometric training were ranked fourth and fifth respectively. Other commonly ranked exercises modalities were eccentric slide boards, complex training, fly wheel training and velocity-based training.

Coaches were asked to detail their top five most frequently used exercises. The most selected exercise was the trap bar or hex bar deadlift with 26 (51%) out of 51 coaches incorporating this exercise into their programmes. Romanian or stiff leg deadlift variations (N=22, 43%), barbell squat (N=21, 41%), rear foot or split stance squat variations (N=20, 39%), Nordic hamstring curls (n=15, 29%) and hip thrusts (n=13, 25%) were the other most frequently used exercises. Numerous other exercises were also ranked in coaches' top five exercises, including: eccentric hamstring curls, calf raises, lunge patterns, isometric hamstring holds, step-ups, Copenhagen adductor holds, single leg jumps, and derivatives of Olympic Weightlifting, such as jump shrugs, hang cleans and drop snatches.

STRENGTH AND POWER DEVELOPMENT: PLYOMETRICS

In the following section participants were asked if they incorporated plyometric exercises into their S&C programme and, if they did, the reasons why. One hundred percent (n=50 of coaches who answered reported using plyometrics, with one coach not answering the question.

In terms of plyometric rationale, 68% (n=35) of coaches reported using plyometrics for improving rate of force development, 49% (N=25) for improving reactive strength, 43% (N=22) for training the stretch shortening cycle, 41% (N=21) for improving stiffness, and 29% (n=15) for injury prevention. Other answers were 'improving vertical jump', 'upper body power', 'speed development' and 'full body power'.

The second question in this sub-section asked coaches how they integrate plyometric training into their S&C programmes. Forty-seven percent (N=24) of coaches stated that it is 'dependent on the individual athlete'. Twenty-nine percent (n =15) of coaches reported that 'plyometrics and resistance training are done as complex training during the same session', 27% (n =14) 'only included on the grass during the warm-up', and 22% (n =11) state that plyometrics are completed 'on separate days to resistance training'. Other responses included 'depends on the phase of training as to when they are included', 'pre-training to potentiate speed drills' and 'incorporated within sprinting sessions'.

The third question in this sub-section asked coaches to identify the types of plyometric exercises regularly used in their sessions. Figure 6 highlights the responses from the coaches. Other select responses include 'proprioceptive ancillary drills for stiffness' and 'ankling warm-ups'.

STRENGTH AND POWER DEVELOPMENT: ECCENTRIC TRAINING

In the following section, participants were asked if they incorporated eccentric overload exercises into their S&C programme and, if so, the reasons why. Forty-five out of 51 (88%) coaches reported using eccentric exercises. Forty (78%) coaches reported using eccentrics for preventing injuries. Twenty-five (49%) coaches used eccentric exercises as 'they follow the recommended advice given in available literature', 15 (31%) used them as they 'can provide the exercises in environments away from the gym', 12 (24%) responded: 'we can use only a few exercises to get a significant physical adaption in our players' and 7 (14%) used eccentric exercises as 'players find it useful'.

Six (12%) coaches reported not using eccentric exercises. The main reason given was: 'we don't have time to recover from eccentric overload exercises during the season'. Other responses included: 'we don't have the equipment to test eccentric strength', 'maximal effort eccentric work provides too much DOMS', and 'players have a negative perception of the eccentric exercises, such as the Nordic'.

STRENGTH AND POWER DEVELOPMENT: PERIODISATION

The next sub-section related to periodisation strategies used to implement S&C sessions. Eighty-four percent (n=43) of coaches answered that 'yes' they do use a periodisation strategy; 16% (n =8) said 'no' they did not. Sixty percent of those who implement a periodisation strategy responded that 'periodisation helps target a specific outcome of a specific period'. Other answers were: 'periodised training offers superior developments of strength, power and performance variables" (N=22); 'it helps prevent stagnation or boredom' (n=11); and it is 'vital to know when to add or delay changes in the programme' (n=10). The main reason as to why a periodisation strategy was not incorporated was 'too many external variables interrupt any pre-planned periodisation strategy' and 'players don't perform enough S&C to follow a true or traditional periodisation strategy' (n=4). Other responses included: 'too many matches', 'our sessions incorporate most aspects of athletic development' and 'we don't follow a traditional model of periodisation'.

STRENGTH AND POWER DEVELOPMENT: SPEED DEVELOPMENT TRAINING

In the following section participants were asked which forms of training were used for targeting speed development, when this occurred, and how often they were trained.

Information regarding the type of speed development exercises most frequently used by football S&C practitioners are highlighted in Figure 7. The second question in this sub-section asked coaches how they integrate speed development training into their S&C programmes. Information regarding how speed development training is integrated into S&C programming in relation to resistance training session is highlighted in Figure 8. The final question in this sub-section asked practitioners how often these speed development modalities were specifically targeted in the training schedule.

When specifically targeting acceleration, the most common response from practitioners was 'once a week' (n=17). Thirteen coaches specifically targeted acceleration daily, and 12 twice a week. When specifically targeting change of direction speed (CODs), the most common response from practitioners was 'twice a week' (n=17). Sixteen coaches specifically targeted CODs 'once a week', and nine daily. When specifically targeting deceleration, the most common response from practitioners was 'once a week' (n=19). Fifteen coaches specifically targeted deceleration twice a week and nine daily. When specifically targeting high speed running, the most common response from practitioners was 'twice a week' (N=24). Eighteen coaches specifically targeted high speed running once a week, and six did the same three times a week. When specifically targeting max speed, the most common response from practitioners was 'once a week' (n=35). Ten coaches specifically targeted max speed twice a week, and two fortnightly. When specifically targeting repeated sprint ability (RSA), the most common response from coaches was 'once a week' (N=24). Seven

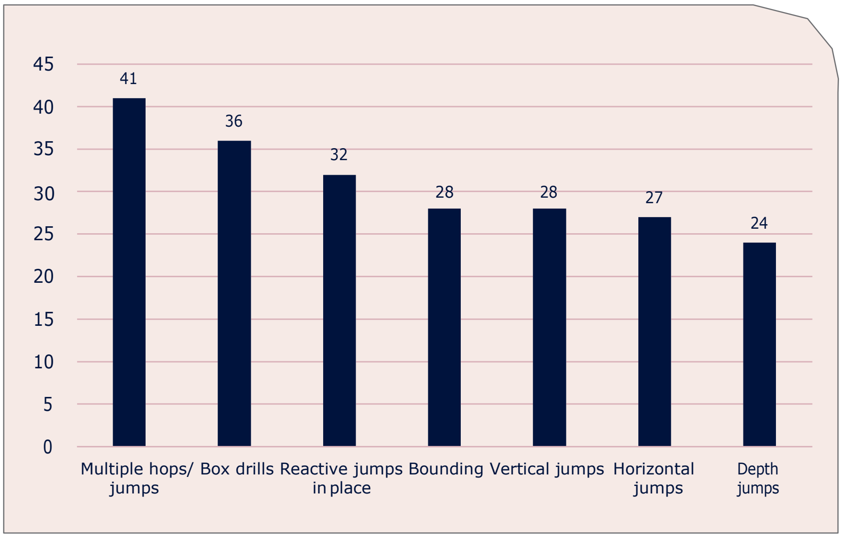


Figure 6. The type of plyometric exercises most frequently used by soccer S&C coaches

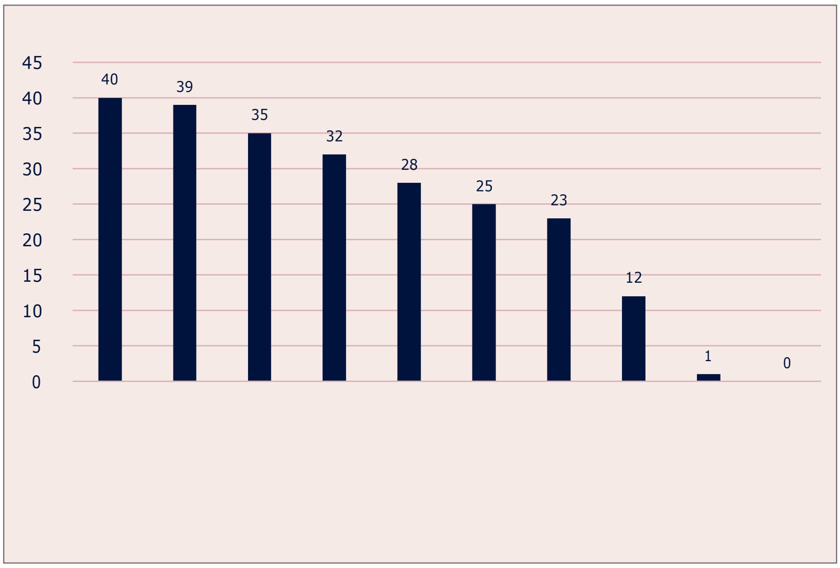


Figure 7. Exercises used by strength and conditioning coaches for speed development training

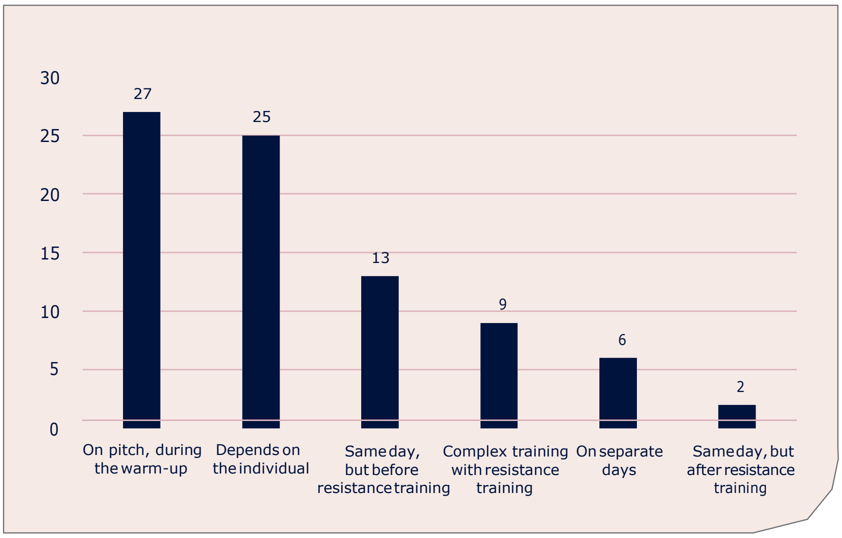


Figure 8. How coaches incorporate speed development sessions in relation to resistance training

coaches specifically targeted RSA twice a week, and six fortnightly and monthly.

CURRENT ISSUES AND BARRIERS TO PRACTICE

The fourth section of this survey elicited responses from coaches regarding attitudes, experiences and barriers facing the delivery of S&C practices in football. This aimed to address attitudes – not only of the players but also of other key people who facilitate the success of any strength and conditioning programme.

The first question in this section asked coaches if they thought there had been a positive change in attitude from players and management towards S&C practices. Forty-eight (94%) of coaches believed there has been a positive change in attitude from players towards S&C practices during their time working in football. Two (4%) coaches were 'unsure', and one coach suggested 'definitely more buy-in across the squad as a whole, but is this because the players are more conditioned to just do as they are told?'

Forty-two coaches believe there has been a positive change in attitude from senior management/staff towards S&C practices during their time working in football, with three suggesting there hasn't been, and one 'unsure'. Four coaches gave more detailed responses including: 'in my current club yes, but when working at a bigger club, senior staff did not believe there was a benefit to strength training', 'depends on the management', 'still considered behind physio as it's an older discipline. Some coaches also not interested in what we can help them with', and 'different staff have different views and expectations'.

Table 3. Challenges facing delivery of S&C practices at responders' clubs

CHALLENGES	RANK 1	2	3	4	5	WEIGHTED RANK (SCORE)
Lack of time between matches	8	7	6	5	4	1
Importance of winning	2	7	3	4	4	2
Lack of or poor facilities	6	1	4	3	5	3
Lack of staff	5	2	7	1	0	4
Players' previous negative experiences	2	5	4	3	6	5
Constant changes in management	4	2	1	5	4	6
None – we have good adherence and no challenges	6	0	3	1	3	7
Lack of appreciation and understanding of role	2	4	2	1	1	8
Lack of player understanding or buy-in	1	4	1	4	1	9
Trying to keep things fresh	3	0	4	1	3	10

Table 4. Perceived challenges facing delivery of S&C practices at other clubs

CHALLENGES	RANK 1	2	3	4	5	WEIGHTED RANK (SCORE)
Constant changes in management	12	4	1	4	1	1
Authority over implementing practice	6	6	2	1	2	2
Importance of winning	3	3	4	9	2	3
Integration with coaching staff philosophies	3	4	4	2	7	4
Lack of time between matches	1	3	10	2	3	4
Lack of or poor facilities	3	6	1	3	3	5
Lack of staff	2	6	4	0	2	6
Lack of appreciation and understanding of role	4	3	2	3	3	7
Difficulty quantifying benefits	3	2	6	0	4	8
Lack of support from management	3	3	2	4	3	9
Lack of player understanding or buy-in	2	1	4	2	1	10

The second question in this sub-section asked coaches for their experiences with the challenges they faced in delivering S&C practices, as well as their opinion on the challenges facing S&C delivery for all other S&C coaches in football. Ranked weighted order (weighted average) responses show that lack of time available between matches was deemed the biggest challenge facing coaches in providing effective S&C programmes in their own organisation. Table 3 details the top 10 challenges facing delivery of S&C practices at clubs. Other selected responses included: 'integration with coaching staff philosophies', 'authority over implementing practices' and 'too much travelling'.

Table 4 details the ranking of the top 10 perceived challenges facing delivery of S&C practices in football as a whole. Responses showed that 'constant change in management' is believed to be the main challenge facing football as a whole. Other selected responses included 'players getting input from external coaches' and 'players' previous experiences'.

The final question in this subsection related to the most valuable method for creating a positive buy-in or attitude towards strength and conditioning practices. Results show that 46 (90%) coaches believed 'building trust and effective relationships with players' to be the most valuable method for creating a positive attitude towards S&C. A total of 41 (80%) coaches reported 'effective communication with athletes' as the second most valuable method for creating a positive attitude towards S&C; in contrast, 37 (72%) coaches reported that 'showing the player how gym based exercises will translate to on-pitch improvements', 35 (69%) coaches suggested 'the ability to vary coaching style to different athletes' and 'building trust and relationships with staff' are all important factors in creating positive attitude towards strength and conditioning practices. Programme design (n=14, 27%), exercise selection (n=11, 21%), and use of the latest technology (n=4, 8%) were other factors to be considered.

DISCUSSION

The present study sought to conduct a comprehensive survey of S&C practices in senior professional male football; to the authors' knowledge, this is the first such assessment. It is also the first assessment to investigate the concerns and challenges that practitioners face when trying to implement S&C practice, although some have been reported in injury prevention studies. Seventy-four practitioners working in professional, senior male football were invited to participate and 51 responded (69%). Although this may be lower than some previous response rates within similar studies in other sports (47-87%),[22,23,40,73] this is the highest number of respondents obtained in a study examining S&C provision in a single sport to date. Previous studies examining S&C practices in various sports have received between 20 and 43 responses.[22,23,24,34,40,73] In similar reports into injury rates in professional football, response rates were 44 (53) and 32.[54] As such,[51] responses at a return rate of 69% were deemed sufficient for analysis and is the highest number of respondents to a survey of S&C practices.

All respondents supported athletes in professional, senior male football. There were nine respondents from the English Premier league, 17 from the English Championship, 8 from League One, 7 from League Two, 3 from Scottish Premiership, 6 from Major League Football (USA) and 2 from the National League. The data presented in this article are therefore truly reflective of elite, senior male football.

Respondents were also experienced in the field of S&C, with an average time working in football of 9.61 ± 5.65 years; in addition, they had worked in their current role for 2.97 ± 2.79 years. This level of experience is similar to those coaches who responded in similar research in different sports.[23,24]

Respondents were also experienced in the field of S&C, with an average time working in football of 9.61 ± 5.65 years; in addition, they had worked in their current role for 2.97 ± 2.79 years. This level of experience is similar to those coaches who responded in similar research in different sports.[23,24]

STRENGTH AND POWER DEVELOPMENT

There is great variance in the physical qualities required for successful football performance;[47,61] also, the increasing physical requirements in elite football[7,9] suggest that the inclusion of S&C practices would be beneficial to help players cope with this demand. Research indicates that football performance requires a level of contractile strength which can be improved through S&C practices. Lower limb strength training, such as sprint speed and jumps,[15,36,70] has been shown to have a positive influence on football-specific movements and is seen as an important factor in physical success.

'This is the highest number of respondents obtained in a study examining S&C provision in a single sport to date'

In this survey, 100% of coaches who responded indicated that lower limb strength training was regularly incorporated into their programmes, with 88% stating that sessions are compulsory. In addition, a total of 86% of practitioners believe strength training is very important (63%) or important (23%) for football performance. The most common reason for incorporating lower limb S&C training was to 'help develop the physical qualities needed to play the game'.

In this study, practitioners stated that the main focus of their S&C programmes was to: 'prioritise performance enhancement strategies' (n =25, 49%) rather than 'prioritising injury prevention or reduction strategies (n=17, 33.3%). Previous research in football has focused on injury prevention strategies[53,60] and the practices that are perceived to help this. This could suggest that injury reduction is the primary goal of S&C interventions in football. However, our study clearly contradicts this and provides information regarding S&C in football that has hitherto been unreported: this has implications on the types of practices deemed to be most effective in football.

Although not reported in football, well-developed lower-body strength, repeated sprint ability and speed have all been shown to be associated with a greater tolerance to higher workloads, as well as a reduced risk of injury in team-sport players.[50] Also, elite rugby league players, with greater high-intensity running ability and lower body strength, have been shown to experience smaller decrements in peak power output post-match.[39]

The role of muscle strength and muscle imbalances as risk factors for lower limb injuries has been widely discussed.[17,31,53,54] In fact, muscle imbalances have previously been ranked as the third most important intrinsic risk factor for injury in elite male football.[53,54] Adequate training to improve muscular strength has been reported as the main measure for reducing these imbalances and reducing injury risk in football players[4,82] and has been shown to reduce injuries to less than one third and over-use injuries almost halved.[44]

The physical demands of professional male football are continually increasing.[7,9] Consequently, improving the ability to not only tolerate these demands, but also to enhance performance, can bring significant benefits to the football club. Lower limb injuries represent a disconcerting cause of time lost from male professional football,[25,27,41] decreased player performance[26,35] and financial cost.[28] It should be noted that reducing a player's risk of injury could in turn be a performance-enhancement strategy in itself. If a player spends more time training and being available for match selection due to a reduction in their injury risk/increase in work capacity, then this should be seen as a performance-enhancement strategy. Moreover, 93% of coaches, staff and players questioned in a recent review[59] suggested that it was the fitness coach's responsibility to ensure 'injury prevention programmes' are put in place.

Although the reduction of injuries is an important factor in success, pushing the boundaries of physical performance to meet, for example, rowing demands, should be a key focus of S&C practitioners in any sport, including football of course. The results of this research are enlightening and suggest that the majority of coaches aim to drive physical performance.

It is clearly, therefore, a dual role of the S&C coach to not only provide effective injury reduction based training, but also to aim to improve the physical capabilities (such as RFD, speed, endurance, strength) of their players.

STRENGTH AND POWER DEVELOPMENT: SESSION DURATION AND FREQUENCY

A typical duration of an in-season S&C session was 30-45 minutes (Figure 2), which appears to be shorter than that reported in other sports. In rugby union, ice hockey and basketball, a typical session is 45-60mins+,[40,24,73] and in rowing sessions can be 60-75mins+.[34] Time available between matches and throughout the training week are reported as challenges to S&C provision, not only in this current research but also in others.[54,57] However, rugby and rowing may not provide suitable comparators. In the case of rugby union, the fixture demand is less than that in football. Often rugby union matches only occur once a week. Rowing, when considered as an Olympic sport, will have long periods out of competition during the four-year Olympic cycle and as such, may have a stronger tradition of S&C practices, and therefore an increase in S&C time and provision.

Twenty-nine (56.8%) coaches reported prescribing strength training two days a week during a two-game week (eg, Saturday and Saturday). The most frequent training day was match day-4 (MD-4), with 46 (90%) coaches reporting they perform S&C on this day. These are similar to those reported in other sports, with 2 d·wk-1 reported as the most common in basketball[73] and ice hockey,[24] but 3 d·wk-1 in rugby union.[40] The review into rugby union was the only other to ask when S&C was incorporated in relation to the next match day, with 85.7% of coaches also reporting MD-4 as the most common day for S&C provision.

In theory, incorporating lower limb S&C on a MD-4 would give the players sufficient time to recover from the previous game (>48 hours) and would give sufficient time to recover and prepare for the forthcoming game (four days later). It has been shown that hamstring strength returns to normal or above baseline at 72 hours post-match in elite youth football players.[16] In theory, in a two-game week, 72 hours post-match would be recorded as a MD-4, ie, a Tuesday, between two Saturday fixtures.

In some football-specific periodisation models, a MD-4 would be considered the biggest training day in terms of training volume. Coaches may not wish to implement strength training the day before a high volume of speed running for fear of residual fatigue increasing the risk of injury or poor performance. A MD-4 may also fall the day before a day off or rest day, so a high volume of combined pitch and gym work would be followed by an adaptation period without fear of being back on the pitch the next day. S&C practices may therefore not only be determined by fatigue and physiological responses to matches, but also by the manager's desired periodisation strategy.

During a three-game week (eg, Saturday and Tuesday and Saturday games),[26] (52%) coaches reported S&C sessions were provided 1d·wk-1, three reported 2D·wk-1, and one reported 3d·wk-1. Twenty (40%) practitioners reported that S&C sessions were not provided at all, but that they 'could be set on an individual basis'. One practitioner did not respond to this question. When asked to provide further details,[14] practitioners reported that only non-starting players completed a session and 16 reported that all players completed at least one S&C session. No other study into football or any other sports has looked at the provision of S&C during a congested fixture week, and as such comparisons are difficult to discuss. However, reasons as to why coaches reported that no players completed an S&C session included: 'lack of time between matches doesn't allow full recovery', 'management wants players to rest or have days off', 'a greater emphasis is placed on recovery strategies', 'not deemed appropriate', and 'no gym-based work, but extended power-based activation is performed on the pitch'. These results provide a useful context for practitioners where the logistical challenges faced in the game provide a limitation to the scope of S&C practice.

'Lowerlimb strength training, such as sprintspeed and jumps, has been shown to have a positive influence on football-specific movements'

‘Eccentric muscle actions involve the active lengthening of muscle tissue against an external force or load’

Hamstring injuries are frequently reported as the most common soft tissue injury in football[27] and muscle fatigue from fixture congestion could add to the issue. Despite the clear concern with high hamstring injury rates, the lack of uptake of the Nordic hamstring protocol (NHE) by Elite European teams is surprising: it has been reported that only 16.7% of teams followed the NHE protocol in part or full capacity.[4] The lack of time between matches could explain this situation. Although suggestions as to why this uptake was so low were not reported in that review, it could be suggested that answers from the current study such as ‘lack of time between matches doesn’t allow fully recovery’ or ‘not deemed appropriate’ may be applicable to the lack of uptake of NHE, as teams surveyed in that review would be consistently playing three-game weeks.

It may also be of note that recent research with elite youth football players suggests that, when combined with adequate recovery, match-play may provide a suitable stimulus for posterior chain muscle strength development.[16] Coaches working on a day-to-day basis may see this as a reason for not including any further stimulus, especially in the posterior chain muscles during a congested fixture week. With time

constraints and busy schedules being a factor for not incorporating S&C, it may be of interest for future research to highlight S&C strategies that can be utilised during these busy periods.

STRENGTH AND POWER DEVELOPMENT: MOST COMMON EXERCISES USED

The trap bar deadlift (TBD) or hex bar deadlift (HBD) was the most commonly used exercise reported in this study; with 26 (51%) coaches incorporating this exercise into their programmes. The TBD was used more frequently compared to a traditional barbell back squat (N=21, 43%) or deadlift. Research has demonstrated that the use of a TBD results in greater force, power and rate of force development (RFD) and has a greater correlation with vertical jump due to similar body positions when compared to traditional squat or deadlifts.[45,74] Hex bar jumps have been shown to elicit greater jump height, peak force, power and peak RFD across varying loads when compared to jump squats.[78] Also, the TBD has been shown to have a 65.8% higher concentric RFD compared to the squat[89] in recreational trained athletes. In the authors’ experience, football players also struggle with hip and ankle injuries and subsequent lack of range of motion that often lead to a poor technical ability in the traditional barbell squat exercise. These limitations can often be reduced by utilising the TBD exercise.

Split stance exercises such as rear foot elevated split squats (RFESS) were frequently reported as the exercise utilised in football S&C coaches’ programmes (N=20, 39%). Although split stance exercises may not allow for the use of high loads compared to bilateral movements such as the squat or TBD, they may still be valuable due to the reported high RFD and their unilateral nature.[89] Unilateral exercises such as split stance squats or step-ups have a relatively high concentric RFD[89] and as such may be useful for training athletic activates such as sprinting or single leg jumps.

In comparison, the only other study that looks at S&C provision in football reported that the leg extension exercise was the most commonly used.[67] Leg extensions have been reported to have a benefit in certain rehabilitation settings, but their benefit in aiding football performance may be limited.[62] This suggests that there has been a change in emphasis since this study as free weight, closed-chain exercises are often considered more functional and beneficial to athletic performance.[6] In support of this,[37] (72%) coaches ranked using free weight (barbell, dumbbell or kettlebell) resistance as the number one resistance modality used in S&C practices.

The use of Olympic style weightlifting exercises was considered less important in football practices than previously reported in other sports such as rugby union (used by 90% of practitioners),[40] rowing (87%),[34] NFL (88%)[22] and NHL (91%).[24] Despite the association between Olympic lifting training and improvements in power output and acceleration,[14,84] the apparent lack of implementation in football practice may be for a number of reasons. This lower usage may also be due to some of the challenges of implementing Olympic lifts into programmes. Olympic lifting exercises such as the clean, snatch, and hang clean are highly skilled, technically difficult and time-consuming exercises to teach.[29,81] With the reported lack of time available considered a challenge to implementing S&C in football, coaches may feel that time could be spent better elsewhere with their athletes. However, it is important to note a potential difference between previous studies that may also explain some of this differential. In some previous studies in rugby union[40] and rowing practices,[34] the squat and deadlift were considered Olympic lifting exercises and as such could be a reason for the higher reported usage of these exercises than in the current study.

Other frequently used exercises included the Romanian or stiff leg deadlift variations (N=22, 43%), Nordic hamstring curls (n=15, 29%) and hip thrusts (n=13, 25%). Numerous other exercises were also ranked in the coaches' five main exercises, including eccentric hamstring curls, calf raises, lunge patterns, isometric hamstring holds, step-ups, Copenhagen adductor holds, single leg jumps, and derivatives of Olympic weightlifting, such as jump shrugs, hang cleans and drop snatches. It should also be noted that, as commented by one practitioner, 'there is a wide range of exercises used' – ie, that there are so many that they couldn't comment on which were the most frequently used. This emphasises that there appears to be a wide range of exercises used within football S&C programmes.

STRENGTH AND POWER DEVELOPMENT: ECCENTRIC EXERCISES

Eccentric muscle actions involve the active lengthening of muscle tissue against an external force or load,[46] in contrast to isometric and concentric muscle actions which involve no change in muscle length or the shortening of muscle tissue,

respectively.[77] It has been reported that skeletal muscle can produce more relative force during eccentric muscle actions compared to isometric and concentric actions[65] and as such the use of many eccentric exercises are gaining popularity during strength and conditioning sessions.

In this research, 45 out of 51 (88%) coaches reported using eccentric exercises, with 40 (78%) using eccentrics for preventing injuries. These results support those previously reported in the literature, where 85% of practitioners believe that eccentric exercises can help prevent lower limb injuries in football players.[59] Eccentric exercises have previously been ranked as the most effective way to prevent non-contact injuries in football players.[53] In addition, it was reported that hamstring eccentrics and the Nordic hamstring exercise (NHE) were ranked third and fifth accordingly. Eccentric exercises have also been ranked fifth for preventing injuries in international football squads.[54] It has been suggested that eccentric exercises may prevent injury by improving the muscles' ability to absorb more force before failing.[43]

A review into the use of eccentric exercise, and in particular the NHE, in 50 UEFA Champions League football teams, suggests that despite the growing body of evidence that promotes the use of NHE in hamstring injury prevention, not many teams actually follow the advice given.[4] A total of 49% of coaches in this current study use eccentric exercises as 'they follow the recommended advice given in the literature'. In contrast, Bahr et al[4] found that only 16.7% followed the NHE protocol in part or full capacity. The contrast in results in these studies maybe due to the lack of specific reference to the NHE exercise in this current study, and just

'In this research, 88% of coaches reported using **eccentric exercises, with 78% using eccentrics for preventing injuries'**

referring to eccentric exercises, whereas the Bahr et al[4] research was specific to the NHE protocol. Results in that study also suggest that clubs use a multitude of hamstring strengthening exercises, including other eccentric exercises such as eccentric leg curls in a yo-yo device, slider board eccentrics and the Askling rehabilitation exercise protocol;[3] therefore uptake of eccentric exercises overall maybe more closely related to those in the current study. In the present study, six coaches reported not using eccentric exercises. The main reason why they are not prescribed was because 'we don't have time to recover from eccentric overload exercises during the season'. Other responses included 'maximal effort eccentric work provides too much DOMS' and 'players have a negative perception of eccentric exercises, such as the Nordic'. These responses are the same as suggestions by Petersen et al[63] and responses in the Bahr et al UEFA Champions League NHE review.[4]

'In theory, by having the athletes perform plyometric **training, they will increase power performance for specific game situations'**

If the advice in the literature for protection of hamstring injuries is to utilise eccentric and in particular NHE exercises, then researchers and coaches should look at ways of incorporating it more. In that respect, a recent study by Cuthbert, Ripley, McMahon, Evans, Haff and Comfort[18] has shown that a lower than expected volume of NHE can still produce adequate strength gains and reduce the risk of HSI in football players. Maybe practitioners need to follow this advice early in pre-season to allow players to adapt to the demands of the exercise before congested season begins.

It could also be noted that S&C programmes need to include a variety of strength exercises, especially for hamstring/posterior chain strengthening. There is much debate around the muscle actions required by the hamstrings during top end running, with some believing it is an eccentric action,[72] and some believing it is more of an isometric action.[87] It is beyond the scope of this review to discuss these matters fully, but what is suggested is that it may be beneficial to include both eccentric and isometric training, as well as traditional eccentric-concentric (isotonic) strengthening and power development exercises in S&C provision for football players. Future research may look to provide further real-world case study examples of in-season strength training programmes that address these issues.

STRENGTH AND POWER DEVELOPMENT: PLYOMETRICS AND SPEED DEVELOPMENT TRAINING

The purpose of plyometric training is to increase the power of subsequent movements using both natural elastic components of muscle and tendon and the stretch reflex.[56] The stretch shortening cycle (SSC) enhances the ability of the neural and musculotendinous systems to produce maximal force in the shortest amount of time.[51] This has prompted the use of plyometric training as a bridge between strength and speed.[51] As football is made up of a combination of running, jumping, and change of direction movements it would seem logical to include methodologies that enhance this capacity. In principle, the more power the athletes can produce, the better athletic performance they will be able to achieve, which could lead to an increased level of football performance. In theory, by having the athletes perform plyometric training, they will increase power performance for specific game situations.

Fifty (100%) coaches who responded reported using plyometrics; there was one coach who did not answer the question. These results are similar to those in previous studies in other sports; rugby (95%), NBA (100%), MLB (95%), and NHL (91%).[23,24,40,73] The reasons given for the use of plyometrics were 'improving rate of force development' (68%), 'improving reactive strength' (49%), 'training the stretch shortening cycle' (SSC) (43%) and 'injury prevention' (29%). One key factor when considering appropriate plyometric drills is the ground contact time (GCT) involved in the activity. To this end, plyometric activities can be categorised as either slow SSC (>250 milliseconds) or fast (<250 milliseconds) SSC, depending on their GCT.

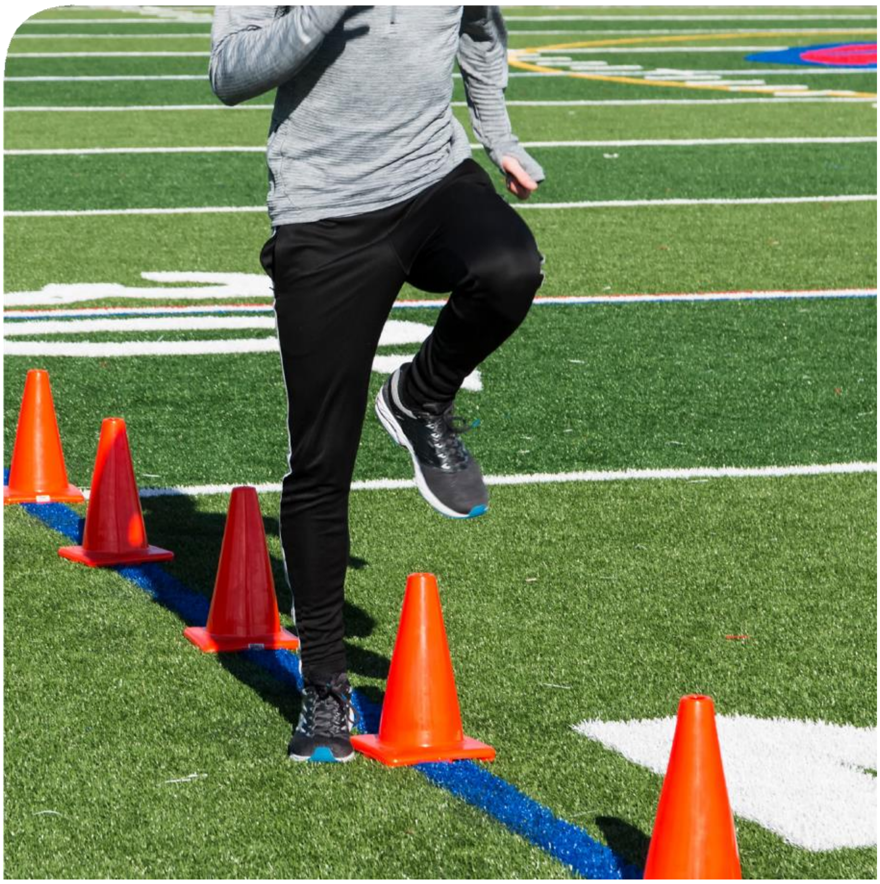
A total of 71% of coaches in this report frequently use box jumps in their programmes. According to Markovic,[52] plyometric training produces greater positive effects in slow SSC jumps, particularly the CMJ, than in the concentric-only jumps (ie, squat jump), or even fast SSC jumps (ie, drop jump).

Although there was unanimity amongst the responses as to the use of plyometrics, there was far more variance in the methodologies deployed. Plyometrics cover a wide range of jumping, hopping, and bounding-based exercises that have the fundamental aim of enhancing SSC performance. The most frequently reported plyometric exercise was multiple hops/jumps, with 80% of coaches (n = 41) using these regularly. Other exercises regularly used were box drills (eg, box jumps) (n=36; 71%), reactive jumps in place (n =32; 62%), bounding and vertical jumps (both n =28; 55%), horizontal jumps (N=27; 47%), and depth jumps (N=24; 47%). Other select responses include 'proprioceptive ancillary drills for stiffness' and 'ankling warm-ups'. These results are highly comparable to reported use of plyometrics in other sports. Box jumps, jumps in place and multiple hops were the most frequently used plyometric exercise in rugby (74.4%),[40] whereas box drills and multiple hops (85%) were second only to upper body plyometric exercises in basketball.[73]

Coaches in this study reported using both vertical jumps (55%), and horizontal movements, such as bounding (55%) and horizontal jumps (47%). Direction of force applied during plyometric or resistance exercises may be considered as a determinant factor of maximal sprint performance.[58] For example, it has been shown that horizontal force production jumps such as broad jumps, and resisted sprints have positive responses in acceleration capacities in elite young football players.[48] Conversely, vertical jumping has been shown to have positive effects on speed at longer distance (10 to 20M),[48] which would be consistent with the increased amount and importance of vertical ground reaction forces during the transition from lower to higher velocities.[52] To this end, the GCT and the type and direction of forces should guide plyometric choice.

Using plyometric exercises was also the main exercise stimulus reported to be used in speed development training (n=40, 78%). Previous studies into other sports have shown that plyometric exercises are frequently used modality in speed development. For example, in rugby union,[40] plyometric exercises were second behind un-resisted or free sprinting – which was third (68%) in the current study in football. In basketball,[743] plyometric training and speed endurance running (90%) are second only to speed or sprint training drills. In this current study, 68% of coaches used un-resisted (free) sprinting and 63% used sprint mechanics/technique running drills to develop speed in football players. Considering that all coaches incorporate strength training practices, with their main focus being performance enhancement, and 95% of coaches using plyometric exercises, it would appear that 68% is surprisingly low for using actual sprint-related drills to improve speed development and may compromise effective speed development.

The second question in this sub-section asked practitioners how they integrate plyometric training into their S&C programmes. A total of 24 coaches (47%) stated that it is 'dependent on the individual athlete'. The individualisation of plyometric programming is far greater in the results of this study compared to those previously reported in other sports. In rugby union,[40] only 13% of coaches integrate plyometrics depending on the athlete's individual needs. Similarly, in the NBA,[73] only 5% of coaches integrate plyometrics depending on the athlete's individual needs.



Fifteen (29%) coaches reported that 'plyometric exercises and resistance training are done as complex training during the same session'. In comparison to similar studies in other sports, plyometrics used as complex training with resistance exercises is a far more common practice. In rugby union, 80.6%,[40] in the NBA 60% of coaches,[73] and in the NHL 56.6%[24] of coaches integrate plyometrics as complex training within strength and power sessions. In NHL,[24] results are closer to that seen in football, with 26.9% of coaches integrating plyometrics as complex training.

In this study, 14 (27%) coaches only include plyometric exercises 'on the grass during the warm up', and 11 (22%) state that plyometrics are completed 'on separate days to resistance training'. In comparison, in rugby union, 6.5% of coaches integrate plyometrics only 'within on-field warm-ups.[40] Other responses included 'depends on the phase of training as to when they are included', 'pre-training to potentiate speed drills' and 'incorporated within sprinting sessions'.

The next question in this sub-section asked practitioners how they integrated speed development training into their S&C programmes. Twenty-seven (54%) coaches reported that 'speed development training is only included on the grass, during warm-up or conditioning drills'. Twenty-five (49%) coaches stated it was 'dependent on the individual athlete', 13 (25%) reported that 'it is done before resistance training, but on the same day', 9 (17%) reported that they included speed training 'in complex training during the same sessions as resistance training', and 6 (11%) state that it is done on 'separate days to resistance training'. Only two (4%) coaches reported that 'speed development training is done on the same day but after resistance training'.

Despite previous studies in other sports highlighting the use of speed development sessions, no data have been produced showing how they can be integrated into daily or weekly practice.

STRENGTH AND POWER DEVELOPMENT: PERIODISATION

Periodisation is a theoretical model that offers a framework for the planning and systematic variation of an athlete's training prescription.[10] Periodisation was originally developed to support the training process in track and field or similar sports in which there is a clear overall objective such as training tailored towards a major championship such as the Olympics.[66] The inclusion of variation in the prescribed training load is thought to be a fundamentally important concept in successful training programmes.[32] Sustained exposure to the same training load can fail to elicit further adaptations as an athlete adapts to the stimulus. Sustained training loads, especially if they are high, can also lead to fatigue and injury.[57] Both these outcomes would result in ineffective training sessions and a failure to benefit performance of both the individual athlete and the team.[57]

Training studies normally show that periodised training elicits improved responses when compared to groups employing a constant load.[30,76] Consensus has thus largely been reached among researchers and practitioners that periodised training offers superior development of strength, power, body composition, and other performance variables.[30,75,76]

Forty-three of the 51 respondents (84%) reported implementing periodisation strategies in their S&C programmes. This practice is lower, but similar to that of coaches in rugby union (90%), rowing (97%), NBA (91%), NHL (90%), and MLB (83%).[40,34,73,24,23] Eight (16%) answered 'no', they do not use a periodisation strategy. The main reason (N=26, 51%) given for implementing a periodisation strategy was that 'periodisation helps target a specific outcome at a specific period'. Other answers were that 'periodised training offers superior development of strength, power and performance variables' (N=22, 43%), 'it helps prevent stagnation or boredom' (n=11, 22%), and it is 'vital to know when to add or delay chances in the programme' (n=10, 20%).

A major obstacle for coaches working in seasonal team sports is the frequent matches and extended competition period. Football players need to attain multiple physical training goals within similar time periods and a competitive fixture schedule that requires multiple (around 40-50) peaks across a 10-11 month season. This is supported by the responses provided in this research. The main reason as to why a periodisation strategy was not incorporated was 'too many external variables interrupt any pre-planned periodisation strategy' and 'players don't perform enough S&C to follow a true or traditional periodisation strategy'. Other responses included 'too many matches', 'our sessions incorporate most aspects of athletic development' and 'don't follow a traditional model of periodisation'. A potential complication here is what is considered to be periodisation. Traditional periodisation strategies often focus on a particular component of training for approximately four weeks, utilising a 3:1 loading paradigm whereby progressive loading is applied for weeks 1-3 and week 4 is a de-load. However, there is a general lack of evidence for the direct application of traditional periodisation models to team sports such as football.[32]

If coaches were to follow the classic model, training would taper considerably for the duration of the competition phase and this would be hugely counterproductive for most team sports.[5,37] Therefore, a non-linear or conjugate periodisation, which involves the variation of load and volume on a session-by-session basis, is more appropriate to team sports during the in-season.[33] It could be that this type of approach is actually deployed but was not considered as periodisation by the 16% of responders who reported not using periodisation.

Periodisation in football has previously focused on the on-pitch conditioning of players.[49] This may be due to the fact that in order to optimally prepare players to undertake the different positional match demands, specific physical and technical football drills are implemented to achieve these key physiological requirements. It may also be because coaches often see the on-pitch technical, tactical and physical work to be of greater importance than gym-based activities. Although it is clear that some general concepts associated with periodisation (for example, the division of the year into phases of training; namely pre-season, the competitive season, and the off-season) are applied within the elite professional game, there is little evidence for the wholesale application of the traditional methods of periodisation.

Therefore, relatively little information is available, either in the literature or applied professional journals, that provides a detailed outline of the longitudinal gym-based S&C training loads experienced by players in football.

CURRENT ISSUES AND BARRIERS TO PRACTICE

It is well known that football schedules are often congested, chaotic and at constant threat of changing due to several factors such as television coverage and progression in one or a number of knockout tournaments. Issues around fixture congestion are impossible to change, as the nature of the sport can require teams to play 2-3 games per week for the vast majority of the season.[2,83] This is the case for not only the elite teams playing in European competition, but also those in English domestic leagues, due to involvement in multiple cup competitions on top of a 38-46 game league season. It becomes difficult to periodise, manage training load and avoid accumulated fatigue, while ensuring that players remain at an optimal level of physical fitness during the season.[2]

It is therefore no surprise that time available between matches was reported as the biggest

> 'building relationships and effective communication stylestoallow playersto see the transfer **of gym work to on-field performance would be highly advantageous'**

‘if the requirement in professional football is to improve performance and help prevent injuries, then organisations may need to employ more qualified staff in strict S&C roles’

challenge facing the implementation of S&C practices by practitioners in this study. It was also the second ranked perceived challenge facing those at other organisations. Reduced recovery time and congested match schedule are highly ranked perceived extrinsic risk factors for injury in top-level football.[53] Responses in this study are in line with those previously reported into injury prevention strategies and on-pitch conditioning.[8,19,49,53,54] In agreement, 33 (64.7%) coaches in this survey suggest that the increase of in-season fixtures is a cause of increased injury risk.

Additionally, the importance placed on winning matches, which was ranked second in barriers to practice, is a barrier that will prove very difficult to change. The overall aim of senior professional sport is to win, and support staff operating within these organisations should always remember that winning is often deemed more important than the process of getting there. The importance of winning matches has previously been highlighted as a barrier to physical fitness development;[49] in this current report, one practitioner suggested that S&C coaches ‘need to understand that we are part of football performance, not just gym performance’.

However, ‘lack of staff’ or ‘lack of or poor facilities’, which were third and fourth ranked responses in this survey, are something that can be managed. If performance, injury rates and time lost to injury are all important factors to winning matches,[35] then employing qualified staff and providing adequate training facilities should be of high importance to senior club staff. Lack of staff has previously been highlighted as a substantial barrier to the effectiveness of any training load monitoring practices in football.[1] Hägglund et al[35] have previously described how a low incidence of injuries and team success are correlated, whereby teams with fewer injuries have better results in both UEFA tournaments and in national leagues. The results from this study should provide clear motivation for coaches and managers to work together with medical teams to help prevent injuries. Although not reported in this study, from the authors’ experience, many football clubs especially in the lower tiers of English football may not have their own training facilities. Often clubs will use local leisure centres, universities or public fitness centres for their S&C sessions, which all provide barriers to the effective application of strength and conditioning.

Within the 51 clubs who responded to this study, there was a total of 452 staff employed. However, S&C coaches were the least represented out of all the professions, with only 10.6% (n=48) compared to 27.2% (N=123) physiotherapists, 15.3% (n=69) sports scientists and 14.3% (n=66) soft tissue therapists. Clearly S&C still has a long way to go before it is fully accepted as a key part of a performance team. This is further emphasised by the fact that there were less reported paid S&C coaches than interns (n=61, 13.5%) within the 51 clubs who replied, further emphasizing the potential lack of importance placed on strength and conditioning.

However, although we did not ask the question, it is always possible that some sport scientists, physiotherapists and interns take the role of S&C coaches in some organisations and therefore these numbers may not be truly representative of the landscape. Clubs in the lower tiers, or those with less finance, may utilise some staff in a dual-role capacity. Some sports scientists and S&C coaches may often have inter-changeable job titles depending on the organisation. For example, someone whose job role is primarily that of an S&C coach, may in fact have the job title of sport scientist or fitness coach. The fact that 112 members of staff hold a S&C-related certification, but only 48 (43%) are classified as S&C coaches may bear this out. However, if the requirement in professional football is to improve performance and help prevent injuries, then organisations may need to employ more qualified staff in strict S&C roles. In fact, when given the option to provide an insight into the future of S&C in football, several practitioners provided answers that support this argument. Responses included: ‘the increased demands of the game and athletes will improve buy-in’, ‘with players becoming fitter, faster, stronger, the role of the S&C coach will become more vital', and 'hope that S&C coaches get the same recognition in terms of salary and respect as other medical staff'.

Given that S&C has yet to be fully accepted in football, an important role for a coach is to convince key people of the potential impact S&C practices can have on football performance. Consequently, coaches were asked about their methods for creating a positive buy-in or attitude towards S&C practices. Results show that 46 (90%) coaches believe 'building trust and effective relationships with players' to be the most valuable method for creating a positive attitude towards S&C. Forty-one (80%) coaches reported 'effective communication with athletes' as the second most valuable method for creating a positive attitude towards S&C. These responses could be of interest to current and up-and-coming coaches.

On the other hand, programme design (n=14, 27%), exercise selection (n=11, 21%), and use of the latest technology (n=4, 8%), all areas that are typically associated with superior strength and conditioning programming, were actually lower ranked responses. Instead, it was communication, relationships and approach to players and staff that were deemed more important. Often, S&C professionals are encouraged to think it is the choice of exercises that make a successful programme, but coaches working in elite football suggest differently. No survey into other sports has asked this question before, and as such, the findings relating to S&C practice in football are novel to this report, and crucial if the field is to develop suitably skilled coaches.

As a result, universities, coaching organisations such as the NSCA or UKSCA, and other educational providers should be encouraged to incorporate more communication style and relationship building education into their courses rather than focusing solely on the importance of exercises per se. Interestingly, previous research with elite athletes has shown that – while instruction, technical knowledge and feedback are essential in delivery effective S&C coaching – athletes suggest that trust, respect and relationship with the coach have an important role in a successful programme.[79]

Thirty-seven (72%) coaches reported 'showing the player how gym-based exercises will translate to on-pitch improvements' as an important method for creating a positive attitude towards S&C practices. The transfer from 'gym strength' to on-field performance is supported by the training principle of specificity, which states that the closer the strength training resembles a sport movement, the greater the transfer of strength is, particularly in elite athletes.[90] Muscle recruitment patterns associated with a strength training task should be comparable when expressed during the sport movement.[13] For example, this would include the direction of force, velocity of movement and muscle contraction types[42] being similar in gym-based movements to those performed on the pitch. Research into a number of elite sports (track-cycling, kayaking, rowing and athletics) has shown that S&C coaches believe that in order to gain the biggest transfer from gym strength to performance strength, there needs to be a strong combination of non-specific strength training and resisted sport movement training, such as resisted rowing, resisted running or over-geared (increased resistance) pedalling.[11]

Taken together, it could be suggested that to create a positive buy-in from players to help develop a successful S&C programme, building relationships and effective communication styles to allow players to see the transfer of gym work to on-field performance would be highly advantageous.

Practical conclusion

This study is the first to describe the S&C practices of coaches supporting football athletes in the UK and North America. As respondents supported professional senior male level football players, practitioners now have a source of data describing S&C at the elite end of football. Coaches and sports science practitioners who work with football athletes at all levels can use this summary of S&C practices as a resource to inform and improve their practices. Information presented in this article may also influence the design of experimental protocols in future studies investigating effects of conditioning interventions on physical performance variables associated with football performance.

There are currently some recommendations regarding what exercises could be used to create an effective S&C programme, and how these can be prescribed in professional players (eg, sets, reps, frequency and progression). There is, however, no clear consensus regarding the most effective

'Coaches and sports science practitioners who work with football athletes at **all levels can use this summary of S&C practices as a resource to inform and improve their practices'**

approach to integrating a multidimensional S&C programme into a football season. Similarly, there are no clear guidelines regarding when the programme can be performed in relation to matches or other exercise sessions; for example, during congested schedules when three matches are played per week and recovery time is reduced. Results from this survey highlight when and how practitioners aim to incorporate strength, plyometric, eccentric and speed development sessions into their training schedule. It also reports the variables that need to be considered, and barriers to incorporating practices when trying to include S&C practices. Information in this study has shown that, despite the wide range of exercises available, many coaches use the same types of exercises with their athletes, with a dual focus on bilateral and unilateral exercises.

Interestingly, coaches have shown that communication and relationship-building skills are considered more important at creating player programme buy-in than anything else, including exercise selection. It would therefore be of interest to coaches and researchers to find ways to develop these skills to enhance the success of S&C practices to professional football players.

AUTHORS' BIOGRAPHIES

MIKE BEERE,

MSC, ASCC

Mike has worked for nine years as a senior S&C coach at Cardiff City Football Club. He has a masters in S&C and is currently studying for a PhD in the 'Practical application of S&C in elite football'.

IAN JEFFREYS,

PHD, ASCC, CSCS*D, RSCC*E, FUKSCA, FNSCA

Ian is professor of strength and conditioning at the University of South Wales. He is a former board member of the UKSCA and an assessor and tutor with the Association. Ian is editor of *Professional Strength & Conditioning.*

NICKI LEWIS,

CPSYCHOL, AFBPSS, SFHEA

Nicky is a BPS chartered psychologist and head of therapeutic studies at the University of South Wales. She has previously held roles on the British Olympic Association Psychology Advisory Group and the Welsh Rugby Union Research Advisory Group

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Physical testing and monitoring practices in elite male football

By **Mike Beere**, *Cardiff City Football Club*
and **Ian Jeffreys**, *Setanta College*

OVERVIEW

There is limited published research on strength and conditioning (S&C) practices in elite football. Information regarding athlete testing and monitoring practices would be valuable for both applied practitioners and researchers investigating practices in professional football. The aim of this study was therefore to detail the current testing and monitoring procedures of practitioners working in senior male football.

A questionnaire was developed that comprised the following five sections: 1) why do you use testing and monitoring practices?; 2) what variables are tested during the separate pre-season and in-season phases?; 3) how often are variables tested or monitored?; 4) what is the impact and level of effectiveness of monitoring strategies?; and 5) what are considered the markers of a successful programme? Fifty-one (51 men; age 32.45 ± 7.27 years) out of 74 (68.9%) coaches responded to the questionnaire, all of them working in senior male football for 9.61 ± 5.65 years. All respondents reported using some testing and monitoring practices with the aim of improving performance (n= 43, 84%) and prevention of injury (n=42, 82%). Each team assesses a mean of 9.7 variables during the in-season phase. The majority of practitioners will regularly monitor body composition (86%), training load via GPS data (82%) and heart rate response (74%), player wellness (72%) and lower limb power via CMJ (59%). Athlete feedback and injury rate were seen as the biggest determinants of successful S&C programming. This survey represents new data regarding testing and monitoring practices in elite male football and as such serves as a review of applied information.

Introduction

Physical performance testing is an integral component of an elite football player's development programme.[24,27] The key role of a strength and conditioning (S&C) coach is to help improve physical performance and reduce injury rate.[6] Although designing training programmes appears to be the first step of training management, monitoring the impact of the sessions on players appears to be the second important step towards being successful in the training process.[13] As part of the efforts to maximise performance and minimise injury occurrence, S&C coaches and medical staff will frequently engage in multi-dimensional strategies aimed at the monitoring of player wellness, training load, physical status, strength and readiness to train on a daily basis.[30,48]

Athlete monitoring and training load management has long been a key responsibility for S&C and medical staff.[18] Over the past decade, the emphasis on athlete monitoring in elite sport has risen exponentially, largely from the desire to achieve and maintain performance and mitigate injury risk. Such performance assessments offer an opportunity to evaluate a player's physical qualities, and the derived information can be used to provide coaches and practitioners with evidence to guide talent identification, player selection and developmental programming.[12] Historically, athlete load management relied on coaches' observations. As new technologies for measuring athlete training dose and response surfaced (eg, heart rate monitoring and GPS tracking), the desire to harness and embrace these technologies proliferated their use in S&C, sport science and medical disciplines.[18]

Although improvements in technology such as GPS have allowed the monitoring of training load in greater detail, there are now many variables available with the aim of determining overall training load. In a recent report, Akenhead and Nassis[1] surveyed practitioners working within professional football clubs across the world regarding their implementation of training load management. In total, 56 different training load variables were identified, with teams recording 7 ± 2 variables for training session, and 3 ± 2 variables for competitive matches. Understanding how many and which variables to monitor, and how frequently to monitor is important when trying to decide on the athlete's response to a given training load. Modification of training volume and intensity of both pitch- and gym-based loading (ie, the overall load), throughout periods of the season would help optimise physical performance, reduce accumulation of fatigue and decrease the risk of injury.

Aside from GPS tracking, other common measures associated with player readiness include biomedical markers of stress (eg, creatine kinase;[34] salivary immunoglobulin A (IgA),[37] jump performance,[48] lower limb strength,[29,42] fatigue,[48] and subjective evaluations such as session rating of perceived exertion (sRPE).[19]

Although research has shown how monitoring one measure can highlight an athlete's training response or readiness, it is currently unknown what – and how frequently – assessments are used within the elite football environment. In addition, it is also unknown if assessments of performance such as speed, muscle strength, change of direction or aerobic capacity are tested throughout the season.

Ultimately, the overall aim of any monitoring process should be to provide information to help maintain player performance and availability for competition.[7,20] Given that physical performance assessments are used to inform decision making throughout the player development process,[45] robust interpretation of test performance data is, therefore, paramount.[5] To date, there is no information available that asks practitioners for their opinions on the usefulness of their monitoring data, and if their processes are deemed reliable, informative and valid.

Although physical performance testing and monitoring processes have been examined in many other professional sports such as basketball,[43] ice hockey,[16] American football,[15] rugby union,[25] rowing[22] and cricket,[39] there is limited data available detailing what processes occur in elite football. Additionally, there is no data that exists detailing the frequency of testing assessments, the reasons why such assessments are employed, or what contributes to a successful programme. Therefore, the aims of this research were:

1. To document what testing and monitoring processes occur in professional senior football environments
2. To ask practitioners if the testing and monitoring procedures used actually create an impactful change in performance or practice
3. To question the frequency that testing and monitoring assessments occur during a season
4. To provide new evidence that practitioners in professional football can use to review current practices and also provide new ideas for diversifying/modifying future practices
5. To provide a beneficial resource for football practitioners similar to other sports that can inform coaches for future practice or research

Methods

EXPERIMENTAL APPROACH TO THE PROBLEM

This study utilised a quantitative research design in the form of an online survey to examine the current practices and perceptions of S&C in senior male football clubs in the UK and USA. The survey, 'Strength and Conditioning Questionnaire', was adapted from that commonly used in other sports by Ebben and Blackard.[15] The questionnaire was adapted to be specific to football and to the demands of this research and to test the hypothesis that football S&C coaches follow contemporary, scientifically based principles of S&C. It was hoped that coaches would be willing to share their ideas, practices and perceptions through this survey.

SURVEY

The questionnaire was pilot-tested on a group of five strength and conditioning coaches, academics and researchers to determine the reliability and validity of the questions. Once feedback was received, certain questions were modified. This included changing the order of the questions, so that the logical order would be improved, changing some qualitative questions to quantitative queries and rewording questions to make them more comprehensive. After this, the survey was reassessed by a supervisory panel before being sent to the coaches.

The survey consisted of the following five sections: 1) why do you use testing and monitoring practices?; 2) what variables are tested during the separate pre-season and in-season phases?; 3) how often are variables tested or monitored?; 4) What is the impact and level of effectiveness of monitoring strategies?; and 5) what are considered the markers of a successful programme?

The survey contained seven questions relating to the objectives of the research. It was an online survey, and it was distributed to S&C coaches, sports scientists and medical professionals working in professional senior male football teams in the UK and America via the website sogosurvey.com.

DATA COLLECTION

All subjects were informed of the purposes of the investigation before participating in the study: an initial email or message via social media platforms describing the study was sent to S&C coaches at selected football clubs. This message included a description of the broader study, and an explanation of what the survey would entail. Only those who responded were contacted at a later date, via an email containing an electronic link to access the survey.

The coaches were given 30 days from the time of receiving the email to complete the survey. If no responses were received after 30 days, a reminder was sent for a further 30 days. After 60 days, the questionnaires that were completed were collated for statistical analyses. All data were collected between July and August 2019, with reference to the 2018-19 football season.

STATISTICAL ANALYSIS

All data were collected using an online questionnaire (sogosurvey.com, VA, USA). The survey consisted of a combination of fixed-response and open-ended questions. Data analysis procedures were descriptive in nature with frequency counts and percentages calculated. In addition, some of the questions were scored to produce rank scores, with the frequency count of each response reported, as well as a 5-point Likert Scale set as 1 (not at all) to 5 (very important).

Results

PERSONAL DETAILS

Fifty-one (51 men; age 32.45 ± 7.27 years) of 74 (68.9%) coaches responded to the questionnaire. The respondents consisted of three head S&C coaches, twelve heads of sports science, six heads of performance, eight heads of fitness and one head of medical. Four senior S&C coaches, one senior sports scientist, three first team S&C coaches, five first team sport scientists, one first team physiotherapist, three first team rehab specialists and one assistant S&C coach also responded. Two responders were highlighted as 'other', but no further information was given.

Out of the 51 responders, 45 (88.2%) practitioners were based in the UK, and 6 (11.8%) in the USA. The league levels that the participants worked in are presented in Table 1. On average, participants had been working in professional football for 9.61 ± 5.65 years and had worked in their current role for 2.97 ± 2.79 years.

Table 1. Level of league worked in by coaches who responded

PREMIER LEAGUE	CHAMPIONSHIP	LEAGUE ONE	LEAGUE TWO	NATIONAL LEAGUE	SCOTTISH PREMIERSHIP	MAJOR LEAGUE SOCCER
9	17	8	7	2	3	6

‘it iscurrently unknown what

– and how frequently – assessments are used within the elite football environment’

PHYSICAL TESTING AND MONITORING

Why?

The first question asked why practitioners included testing and monitoring processes, with responses highlighted in Figure 1. The most common response was to ‘improve performance’ (N=42), ‘prevent injury’ (n= 41), and to ‘manage training load’ (n= 39). Two coaches provided additional feedback, stating that they helped ‘provide baseline data for rehab/return to play’, and to ‘monitor the recovery process and readiness to train’.

What?

The second question asked what variables were tested during the pre-season phase, with responses highlighted in Figure 2. The most common response was ‘body composition’ (n=44), ‘CMJ’ (n= 39), and ‘cardiac screening’ (n= 37). Eight coaches answered ‘other’ and provided additional feedback, stating ‘sit-and reach’, ‘MAS runs’, and ‘sub-max runs’ were tested. The third question asked what variables were tested during the in-season phase, with responses highlighted in Figure 3. The most common response was ‘body composition’ and ‘GPS – post session’ (both n=41), and ‘GPS – live feed’ (n= 38).

How often?

In this sub-section, coaches were asked how often testing and monitoring procedures were undertaken throughout the season. When asked how often the players were formally tested for acceleration during the season, the most common response from practitioners was ‘never’ (n=17). Seven coaches specifically test acceleration at ‘the start of pre-season only’, and six said ‘during international breaks’ and at the ‘end of each periodisation block’.

When asked how often the players were formally tested for agility or change of direction during the season, the most common response from practitioners was ‘never’ (N=24). Seven coaches specifically test change of direction at the ‘end of each periodisation block’, and five ‘during international breaks’. When asked how often the players were formally tested for anaerobic capacity during the season, the most common response from practitioners was ‘never’ (N=20). Six coaches specifically tested anaerobic capacity at the ‘start of pre-season only’, and ‘during international breaks’.

When asked how often the players were formally tested for body composition during the season, the most common response from practitioners was ‘monthly’ (n=33). Six coaches specifically test body composition ‘every other month’, and five at the ‘end of each periodisation block’. When asked how often the players were formally tested for cardiovascular endurance during the season, the most common response from practitioners was ‘on international breaks’ (n=11). Ten coaches specifically tested cardiovascular endurance at the ‘start of pre-season” only, and five at “start and end of pre-season, plus the end of the season”.

When asked how often the players were formally tested for flexibility during the season, the most common response from practitioners was ‘never’ (n=16). One coach specifically tested flexibility ‘weekly’, and six ‘at the start of pre-season only’. When asked how often the players were formally tested for muscular endurance during the season, the most common response from practitioners was ‘never’ (N=22). Five coaches specifically tested muscular endurance ‘during international breaks’.

When asked how often the players were formally tested for muscle power during the season, the most common response from practitioners was ‘at the end of each periodisation block’, ‘monthly’ and ‘never’ (n=9).

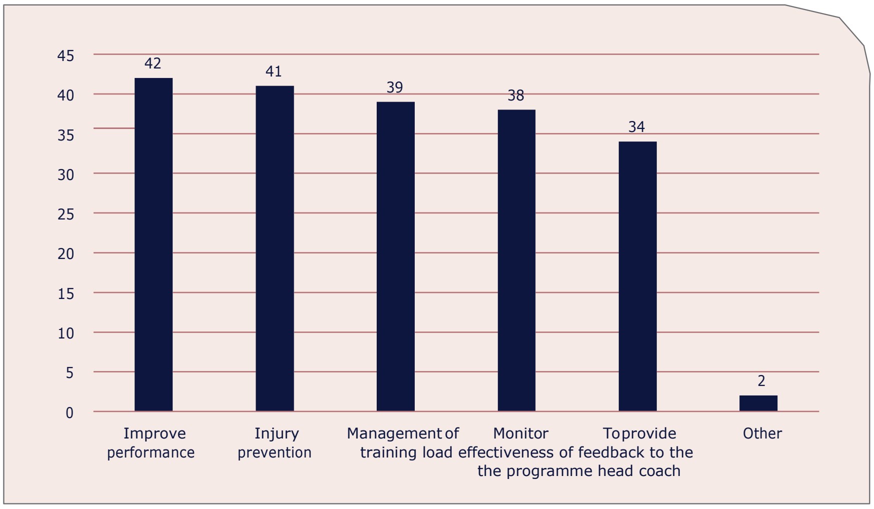
When asked how often the players were formally tested for muscular strength during the season, the most common response from practitioners was ‘never’ (N=12). Ten coaches specifically tested muscular strength at the ‘end of each periodisation block’, and five tested ‘weekly’.

Impact

The next sub-section asked coaches if their testing and monitoring procedures helped to form a meaningful change in their decision-making process. Here coaches provided more than one answer. A total of 23 out of the 51 (45%) coaches stated that ‘all testing and monitoring procedures provide part of an answer to help inform our decision’. Twenty-two (43%) coaches responded that: ‘the majority of testing and monitoring provided part of an answer to help inform our decision’, and 13 (25%) coaches stated: ‘as a sport science and medical team we like to use this data, but senior management isn’t always willing to change training structure based on our results’. Four practitioners stated that ‘only some of our testing helps us inform our decisions’, and two stated that ‘not much of the data is used to force meaningful changes in our actions’. One respondent gave a more detailed answer that ‘all testing has a purpose, not all testing changes implementation for all players though. Senior management have the right to decide which bits of information they want to act upon based on recommendations on an individual basis'.

Accuracy and reliability
Coaches were asked if they believed that their testing markers were accurate, reliable and validated in order to determine the success or failure of the programme. A total of 36 (71%) coaches replied 'yes', whereas 11 stated that 'no', they did not believe their testing markers to be accurate. Five coaches gave more detailed answers, which included 'not in all cases'; that 'all testing is statistically flawed in the applied environments and we accept that. Validity and reliability enables us to determine how useful, not how significant a test can be'; that holes had been 'found in all the data'; that 'too many other factors determine the success or failure of a programme'; and finally that 'we've tried our best to generate our own reliability and validity data for all our assessments'.

Markers of success
The final question in this sub-section on testing and monitoring asked practitioners what markers or measures the coaches used to determine the success or failure of the S&C programme. The most common response was 'athlete feedback' (N=42), 'injury rate' (n=40), and 'gym performance' (n=38). Figure 4 highlights coaches' responses.



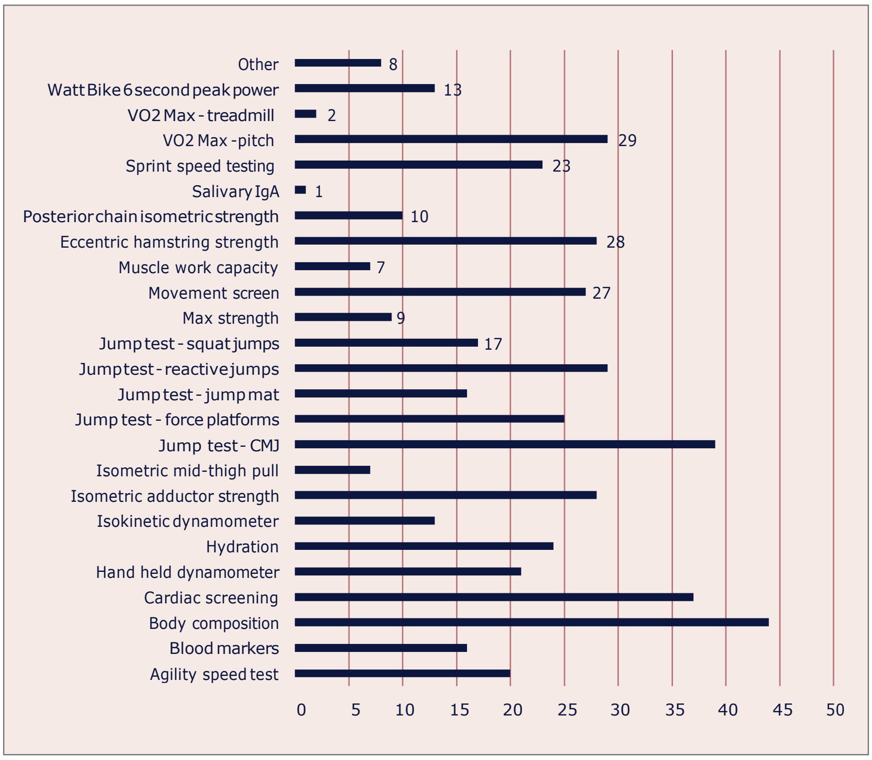


Figure 1 (top): Reasons why coaches use testing and monitoring procedures

Figure 2 (bottom): Most commonly used testing variables measured in pre-season testing

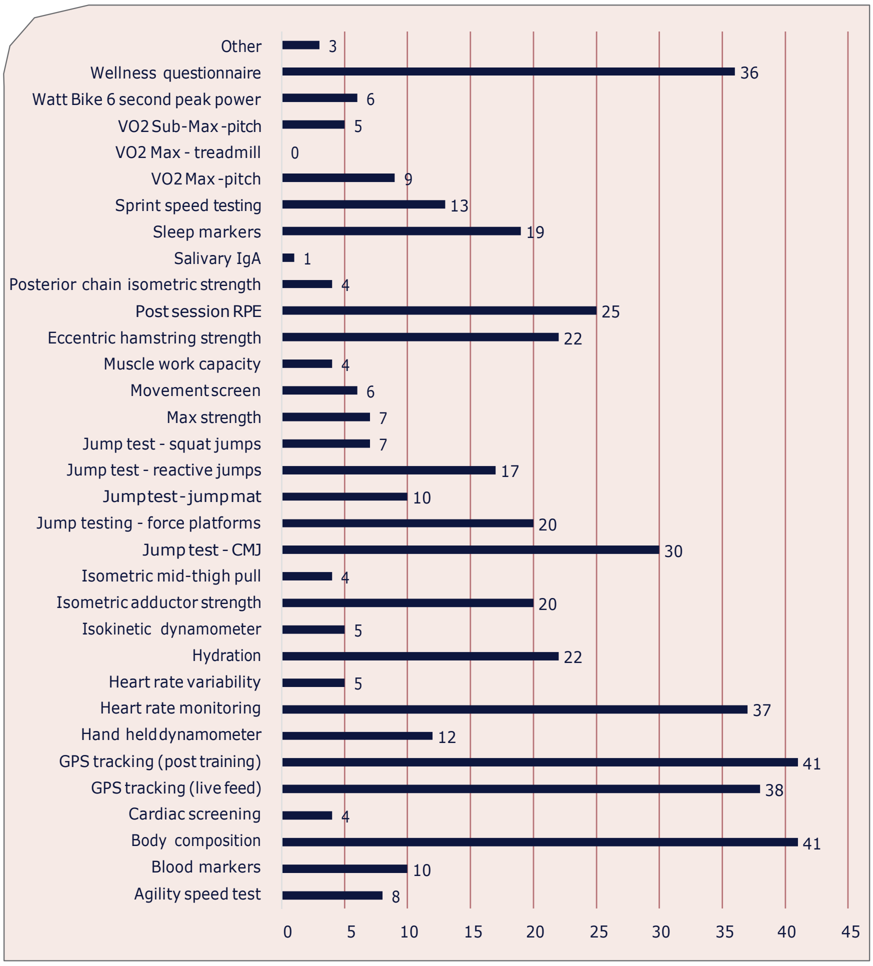
Discussion

The present study sought to conduct a comprehensive survey of strength and conditioning testing and monitoring practices in senior professional male football. To the authors' knowledge, this is the first assessment of testing and monitoring in senior professional male football that highlights the frequency of assessments and the practitioners' opinions on what defines successful strength and conditioning practices. It also expands on the current research into testing and monitoring practices in football.[1,30]

The original findings in this research are that practitioners will test and monitor their players to improve performance, prevent injury risk and manage training load. Results highlight that there is no universally adopted monitoring approach within professional football, although many clubs do adopt similar practices. The majority of practitioners will regularly monitor body composition, training load via GPS data (both 82%) and heart rate response (74%), player wellness (72%) and lower limb power via CMJ (59%).

Assessment of body composition was the most frequently used test to assess the players during the pre-season period, with body composition and GPS tracking most common during the in-season as well. However, in-season testing of physical performance such as speed, change of direction and muscular strength was most commonly 'never' assessed.

Most coaches valued athlete feedback as the biggest determinant of a successful strength and conditioning programme ahead of any other indicator.



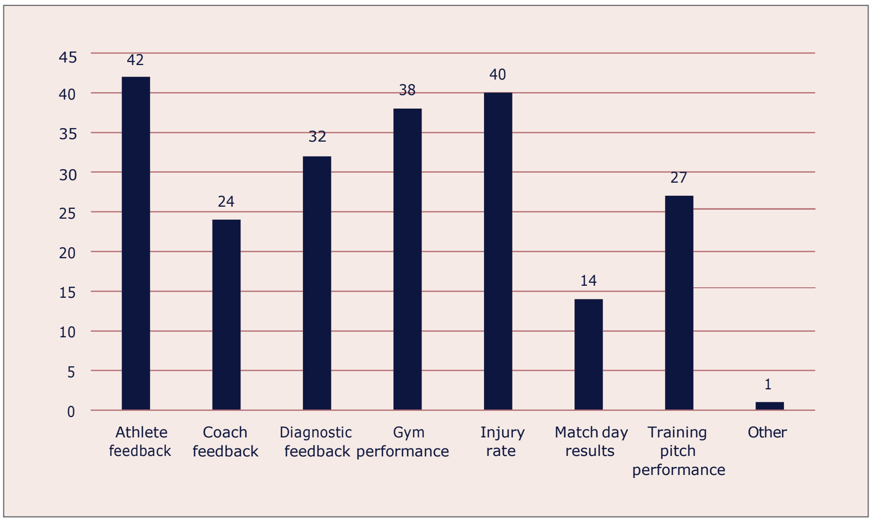


Figure 3 (top). Most commonly used testing and monitoring variables measured in-season

Figure 4 (bottom): Markers and measures used to determine the success or failure of strength and conditioning programmes

Seventy-four practitioners working in professional, senior male football were invited to participate with 51 responding (69%). Although this may be lower than some previous response rates within similar studies in other sports (47-87%), this is the highest number of respondents obtained in a study examining S&C provision in a single sport to date. Previous studies examining S&C practices in various sports have received between 20 and 43 responses.[15,16,22,25,43] In similar reports into injury rates in professional football, response rates were 44,[30] and 32.[31] Also in football, Akenhead and Nassis[1] had a 50% response rate for 41 coaches regarding training load practices. As such, 51 responses at a return rate of 69% was deemed sufficient for analysis and is the highest number of respondents to a survey of S&C practices, especially in elite football.

All respondents supported athletes in professional, senior male football. There were nine respondents from the English Premier league, 17 from the English Championship, eight from League One, seven from League Two, three from Scottish Premiership; there were also six from Major League Football and two from the National League in the US. Therefore, the data presented in this article are reflective of elite, senior male football.

Respondents were also experienced in the field of S&C, with an average time spent working in football of 9.61 ± 5.65 years; furthermore, they had worked in their current role for 2.97 ± 2.79 years. This level of experience is similar to those coaches who responded in similar research in different sports.[15,16]

Testing and monitoring

Physical performance testing is an integral component of an elite football players development programme[24,27] and has shown to be considered important by practitioners in this survey.

Testing and monitoring procedures were incorporated by all practitioners who responded to this survey. This may not be surprising because testing is thought to be useful in identifying team and individual strength and weaknesses; it also helps in goal setting and can be used to assess and demonstrate the efficacy of the programme.[47] In comparison with other studies in football, McCall et al[30] showed that 100% of clubs tested for injury risk during pre-season, 81.2% in-season and 40.9% at the end of the season. Although the McCall study[30] highlighted some strategies used within football, the current report involved a greater depth of questions, aimed to investigate the type of testing used, when it was administered and how often.

In this report, on average, each team tests or monitors 9.8 variables during the pre-season screening phase (total number of answers, 502, divided by 51 respondents), and 9.7 during the season. In a recent review by Drust,[14] the number of testing and monitoring 'touch points' between staff and a Premier League player can range from 3 – 7 per day.

In terms of training load monitoring alone, Akenhead and Nassis[1] found that practitioners recorded 7 ±2 variables when monitoring for training load. This can include readiness to train measurements, field-based monitoring, gym-based monitoring, recovery protocols, match performance evaluation, medical screening and nutritional supplements. This study does not detail the exact tests used, but highlights the amount and range of monitoring processes players have to adhere to per day or week. These results are similar to those previously reported in other sports including Major League Baseball (MLB) (3–4 aspects), National Football League (NFL) (9-10 aspects), National Hockey League (NHL) and National Basketball Association (NBA) (7–8 aspects), rowing (4–5 aspects) and rugby union (11 aspects).

However, comparisons should perhaps be interpreted with caution as the S&C practices in a number of these sports were reported in a period between 2001 and 2005 and it is very likely that assessment batteries in NFL, NBA, NHL and MLB have progressed and been adapted over the past 18 years. Comparisons should also be made with caution as participants in this current study were allowed to select answers from a more comprehensive list of 25 aspects, whereas in many other studies they are restricted to 10-11 options. For example, in rugby union,[25] coaches were only able to select a global term of 'muscle strength testing', whereas in this current research strength testing options were offered in more detail such as 'isometric mid-thigh pull', 'max strength test', 'eccentric hamstring strength' or 'posterior chain isometric strength'. This was because the current authors felt it would give a far greater understanding to the types of tests employed in professional football.

WHY DO WE MONITOR?

The most common reason for including testing and monitoring processes was to improve performance (n= 43, 84%) and injury prevention (N=42, 82%), which is in agreement with previous research.[1] In addition, in the first part of this review,[6] S&C practitioners focus their programming on increasing performance and reducing injury rates. Therefore, it is not surprising that procedures are put in place to monitor these training goals.

Other common answers as to why coaches tested players were 'management of training load' (n=40, 78%), and to 'monitor effectiveness of the programme' (n=39, 76%). Two coaches provided additional feedback, stating that they helped 'provide baseline data for rehab/return to play', and to 'monitor the recovery process and readiness to train'. Monitoring an athlete's 'readiness to train' has previously been shown to be a useful tool in professional, elite football players.[48] This process may involve subjective questionnaires to assess fatigue, sleep quality, delayed onset of muscle soreness (DOMS) and session rating of perceived exertion (s-RPE), as well as heart rate variability and post-exercise heart rate recovery.[48] In previous research in football and other high-performance sports, it has been shown that over half the practitioners use self-reported measures daily to monitor well-being of the athletes.[1,47] Subjective measures have been shown to highlight early risk factors of over-training in athletes before there is a notable drop-off in performance,[7] and as such can be seen as a useful tool to assess player training status.

> 'the current **report involved a greater depth of questions, aimed to investigate the type of testing used, when it was administered and how often'**

WHAT DO WE MONITOR?

Pre-season monitoring

The pre-season period is often considered to be the principal opportunity for physical preparation in team sports.[3,11] As such, practitioners will often collect a large amount of physical screening data that helps with the understanding of the players' physical attributes, injury risk factors and readiness to train to help create group or individual training plans for the forthcoming season.

During pre-season, the most frequently used testing and monitoring tools were body composition testing (n=44, 86%), followed by counter-movement jump (CMJ) testing (n=40, 78%) and cardiac screening (n=38, 74%).

In relation to studies in other sports, vertical or CMJ height is also the most commonly used measure of lower limb muscular power.[25,43] Pre- and post-event jump height may provide valuable data in relation to exercise intensity and athlete neuro-muscular fatigue.[28,33] Immediate post-exercise performance reductions are associated with maximal exertions in individual sports, which include repeated vertical jumps and also non-weight-bearing sports such as cycling.[9] CMJ have a high test-retest reliability score compared with the squat jump and depth jump and is the most valid test for the approximation of explosive power of the lower limbs.[28,40] The CMJ has also been shown to have high

‘Heart rate monitoring was the second most used monitoring tool ... it remains a valuable tool ... to measure the internal response of a player’

correlations to 1-rep-max squat strength, speed and agility,[36,38] and as such it could be argued that only CMJ needs to be monitored, as changes in this variable are possibly indicative of changes in other. Like body composition testing, the CMJ is relatively non-invasive and time-consuming, and as such is a useful marker of physical performance changes throughout the season.

Other common answers were ‘on pitch VO2 Max testing, such as bleep test, yo-yo or 30-15’ and ‘reactive jumps’ (n=30, 58%), ‘eccentric hamstring strength’ and ‘isometric groin strength’ (N=29, 56%) and a ‘functional movement screen’ (N=28, 54%). Eight coaches responded with ‘other’: these answers included ‘sit-and reach’, ‘MAS runs’, and ‘sub-max runs’.

In-season monitoring

The most common markers monitored in-season were body composition and post session GPS tracking, with 42 out of 51 coaches (82%) using these regularly. GPS tracking – live feed (n=38, 75%), heart rate monitoring (n=38, 74%), wellness questionnaires (n=36, 72%), and counter movement jump testing (n = 30, 59%), were ranked 2Nd, 3rd, 4th and 5th accordingly.

As management of training load was reported by 78% of coaches (n= 40) as being the reason why they tested players, the high number of coaches using GPS tracking devices to monitor training is no surprise. The application of GPS tracking devices has provided new insights into both the nature and the intensity of the actions that make up the activities in football training and match play, to determine the overall training load for a squad or individual player.[35] This has allowed practitioners and researchers to think about the ‘loads’ associated with these actions in a more sophisticated way than ever before, so it is of no surprise that they are widely used in football practice[26] and in return to play protocols.[46] These findings are supported by McCall et al,[31] who showed that tracking of minutes played and intensity of work with GPS, along with heart rate monitoring, was one of the most commonly used monitoring tools used by practitioners during the 2014 FIFA World Cup.

In the current study, heart rate monitoring was the second most used monitoring tool, with 74% of coaches (n= 38) using it daily. Heart rate monitors are an accessible and non-invasive tool:[44] data is used to give an indication of the physiological or cardiovascular response of the activity and frequently supplements the movement data collected by practitioners via GPS tracking during training. Despite its limitations in providing an indication of the cardiovascular response to high-intensity intermittent exercises, it remains a valuable tool for the majority of practitioners to measure the internal response of a player.[26]

How often do we monitor?

As previously mentioned, S&C coaches are utilising testing and monitoring processes to improve performance and injury prevention. Although not specifically referenced in this report, the high number of coaches using GPS to monitor training load would suggest that these devices are used daily in relation to training sessions with the aim of managing training load.

Lower limb power was tested with varying degrees of frequency, with the most common response from practitioners being ‘end of each periodisation block’, ‘monthly’ and ‘never’ (n=9). Three (5.8%) coaches also tested weekly, monthly or every other month. CMJ was the 2Nd and 5th most frequently tested performance marker administered during the pre-season and in-season phases respectively. CMJ is the most valid test for the approximation of explosive power of the lower limbs[28,40] and is also the most commonly used measure of lower limb muscular power in other team sports.[16,25] In addition, CMJ is relatively non-invasive and time-consuming, and as such could be a useful marker of physical performance and neuro-muscular fatigue changes throughout the season.[48]

In the current study, body composition was tested 'monthly 'by 33 of the coaches and thus more frequently than all other markers of physical performance. Body composition is the most commonly tested physical marker, with 86% (n=44) and 80% (n=41) of coaches conducting this test during pre-season and the in-season respectively, suggesting that this is seen as a key performance indicator by key decision makers at the various clubs. In other sports, body composition is tested just as frequently during the season, with between 83-100% coaches testing.[15,16,22,25,43] A higher lean muscle mass, and low body fat/adiposity in national level football players has been shown to be to associated with power-related qualities and repeated sprint ability[8] and total distance covered during match play.[41] In addition, Arnason et al[4] reported a positive linear relationship between CMJ, leg power, percent body fat, and team success. Results showed that teams with higher fitness levels and lower percent body fat had a higher league ranking. Monitoring body composition may also be useful for assessing any gains in lean mass following any prescribed resistance type training.

It has previously been shown that a high proportion of practitioners in professional football specifically target speed qualities such as acceleration, max speed and change of direction speed at least once a week during training sessions.[6] However, when asked how frequently these performance markers, in addition to anaerobic capacity, muscular strength and muscular endurance were tested, the most common answer given was 'never'. This does suggest a lack of consistency between the stated performance goals and the methodologies deployed, as these speed and strength qualities are considered important in the sport and have been previously recommended in the literature.[4]

These findings are similar to those reported in other studies in football,[30] where, despite fatigue and fitness being identified as the top risk factor for injury, only 27% (n = 12) of teams tested the associated physical capabilities. Similarly, in the same study although muscle imbalance was identified as the third most important risk factor, only 41% (n=18) of teams used strength tests in their testing protocol. In other sports, such as NHL[16] and NBA,[43] this is also a consistent trend. In basketball, acceleration was the least tested physical variable, and in ice hockey, only 30% tested speed, acceleration or agility despite 95% frequently training these speed qualities.[16,43] It appears that coaches will frequently target training these performance skills, but may test these qualities far less frequently.

Despite the most common answer for testing muscular strength being 'never' (n= 12, 23.5%), a number of coaches (n=10, 19.6%) tested at the end of each periodisation block, or during international breaks (n=4, 7.8%). Although not questioned, each periodisation block could be as often as every 4-6 weeks, and at times, international breaks occur at the same time intervals. If this is the case, then strength testing may actually occur more frequently than initially perceived. International breaks correspond to non-playing weeks for the majority of the clubs surveyed so this would allow for a more suitable time to administer these tests rather than during periods of fixture congestion.

These results are in contrast to those in rugby union, where max speed and power (both 88% of coaches), acceleration and max strength (both 86% of coaches) are the most frequently tested indices.[25] The notable

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'Ultimately, the effectiveness of monitoring is determined by the quality of decisions that arise from it and their impacts'

difference may be due to the perceived differences in physical qualities required in rugby union and football. In rugby union, 41 of the 42 teams, and 38 of the 42 teams test in pre-season and in-season accordingly.[25] However, it is not specifically reported as to how frequently or what measures are taken during the in-season phase, just if testing does take place.

Reasons for the lack of testing of performance markers such as acceleration, change of direction, anaerobic capacity, muscular strength and muscular endurance were not asked in this survey; but it could be suggested that lack of equipment, number of staff, priority in the training week and congested fixture scheduling are all reasons as to why they are not frequently or ever monitored, as these are often reported barriers to the implementation of S&C practices.[1,6,10,26,50] In comparison, body composition testing can be quick, non-invasive and easy to administer within a training day, regardless of fixture scheduling, and as such practitioners may feel it a suitable marker for performance status. In reality, and despite the significant advances in sport science, whereby tests can be administered quicker, and where the knowledge base has grown exponentially, time still remains very limited during the season for a number of reasons. For example, conducting maximal fitness tests (speed, strength etc) may not be deemed appropriate during a season where football teams often play two games per week for consistent periods of time. Therefore, any fitness testing that is conducted, with the possible exception of pre-season, must be streamlined and strategically implemented.

Impact and level of effectiveness of monitoring strategies

The aim of collecting physical performance data is to facilitate evidence-based decision making on overall training load prescription. Ultimately, the effectiveness of monitoring is determined by the quality of decisions that arise from it and their impacts.

Practitioners were asked if their testing and monitoring procedures helped form a meaningful change in their decision-making process. Coaches were able to answer more than one option. Twenty-three (45%) out of the 51 coaches state that 'all testing and monitoring procedures provide part of an answer to help inform our decision'. Twenty-two (43%) coaches responded that 'the majority of testing and monitoring provide part of an answer to help inform our decision', and 13 (25%) coaches stated that 'as a sport science and medical team we like to use this data, but senior management isn't always willing to change training structure based on our results'. One respondent gave a more detailed answer that 'all testing has a purpose, not all testing changes implementation for all player through. Senior management have the right to decide which bits of information they want to act upon based on recommendations on an individual basis'.

This information should be seen as important for the developing practitioner to consider: the data you collect may be important to you but understanding that the manager makes the overall decision is key. Coach buy-in can be seen as a barrier to implementing any data-driven decisions.[1] In many cases it is the head coach/manager who dictates the training programme and therefore determines a large part of the TL. In order for the S&C coach to influence change, coach buy-in and effective communication are essential. Practitioners must have an understanding of the coaches' view on sports science/strength and conditioning and its place in the overall process.

Four practitioners stated that 'only some of our testing helps us inform our decisions', and two said that 'not much of the data is used to force meaningful changes in our actions'.

Coaches were also asked if they believed that their testing markers are accurate, reliable and validated to determine the success or failure of the programme. Thirty-six (71%) of coaches said 'yes', while 11 (22%) stated that 'no' they did not believe their testing markers to be accurate. Unfortunately, practitioners were not asked if any in-house reliability tests were performed to understand the significance of their testing results. However, some practitioners gave further responses stating: 'we've tried our best to generate our own reliability and validity for all our assessments'; that 'all testing is statistically flawed in the applied environment and we accept that', and that 'too many other factors determine the success or failure of a programme'.

In support of some of these responses, research from Akenhead and Nassis[1] suggests that there may be a gap between the expected and perceived actual effectiveness of testing and monitoring at preventing injuries and improving performance. In addition, Carling et al[10] stated that the limitations of tools and protocols combined with concerns relating to the real-world meaningfulness of data, their interpretation and practical application through subsequent interventions are key issues in professional football.

It has been reported that 40% of testing and monitoring procedures are currently limited by methodological or theoretical considerations in professional football.[1] Practitioners also reported that poor validity and reliability of assessments represented a barrier to effective practice. Although the same level of limitations were not reported in this current study, these potential problems may be some of the reasons preventing the widespread application of recommended testing procedures among practitioners. As a consequence of no gold standard measure of football performance, testing and monitoring in football would seem to be not completely driven by the principles of science, but by a subjective individual belief in systems developed through experience and the limitations of the 'real world' working environment. This however, may not be too problematic as research science has yet to understand many well-practiced strategies that are common in many environments.

To identify if a 'true change' in a measure of physical performance has occurred due to a specific stimulus, an understanding of the minimal detectable change in that measure is required.[49] The seemingly low use of such analyses in the club setting may be related to a lack of awareness of the statistical methods, insufficient experience in implementing the method, or perhaps a lack of time and human resources.[1] Clubs and practitioners seeking to enhance the meaning and usefulness of their data may wish to familiarise themselves with these methods or seek outside expertise to assist with this process.

What is apparent is that – although testing and monitoring is common – its impact on practice is less clear and there remains a level of doubt about the full impact of this work.

Determinants of success

The impact of strength and conditioning programming on certain performance markers such as speed, strength, jump height is often reported.[2,21,32] The novel finding in this study is the reporting of what coaches believe to be the determinants of a successful strength and conditioning programme.

Programme or coaching success could easily be measured by match day performance/ results. For example, a successful team is likely to be driven by a successful coach/ manager /coaching setup. Success or failure of a head sports coach/ manager is often viewed almost entirely on won vs. loss records. Too many times, the S&C coach can be part of the 'too much credit' and 'too much blame' syndrome that is persistent in coaching.[23] Interestingly, actual sporting performance whether that be in training, (n= 27, 53%) or match day performance (n= 14, 27%) was ranked at the bottom of the coach's determinants of successful programming in this survey.

Although successful match day performance especially is reliant on a multitude of variables, it could be considered surprising that sport performance was the lowest ranked response within the coaches surveyed. There are strong links between S&C programming and key performance indicators in many sports,[2,11,21,25,32] so it may be amiss not to judge overall programme success on team performance, whether that be actual results or parameters of fitness for example. Conversely, it could be argued that a S&C practitioner's job is not to win matches, but to provide the head coach/manager with the players who are most suitably prepared for each match, for the duration of the season. It would then be the managers' responsibility to select the players, relay tactics, team set-up and instructions for the match itself.

Although match day performance was ranked at the bottom, athlete feedback was

'research science hasyetto understand many well- practiced **strategies that are common in many environments'**

‘As coaches, we could be in danger of focusing on athlete happiness, rather than pushing to reach desired improvements in physical performance’

deemed the most important determinant of a successful strength and conditioning programme, with 42 of the 51 (82%) coaches suggesting this. Unfortunately, this was not an open response question. Athlete feedback could encompass a large range of possibilities. It would have been useful to know if this was the athlete enjoying the sessions because they were engaging, individualised, fun, easy or hard, or if they felt the sessions translated to an improved performance on the pitch. Likewise, feedback could be positive or negative, with both having an impact on the coach’s session design or delivery. Without further questioning, we are unaware of any further detail. For example, the player may provide good positive feedback, but their performance scores may be suffering or stagnating. As coaches, we could be in danger of focusing on athlete happiness, rather than pushing to reach desired improvements in physical performance.

Injury rate was considered the second most important determinant of programming success.

As suggested in this study, performance enhancement and injury prevention are the dominant objectives of the monitoring process, with 84% and 82% of coaches suggesting this respectively. Focus on injury prevention is justified given the associated financial loss and negative impact on team success.[4,17] As mentioned, it is ultimately the S&C coach’s job to provide the coach with as many fit, robust and conditioned players for the longest period of the season. Therefore, ensuring that the players remain injury free is key to this success.

Interestingly, gym performance (n=38, 74.5%), eg, personal bests or weight lifted, and diagnostic testing feedback (N=32, 62.7%) were ranked higher than actual sport performance. This may ask the question, are S&C practitioners chasing ‘gym numbers’ or ‘gym gains’, over actual improvements in sporting performance? However, it could also suggest that sport performance is determined by a wide range of uncontrollable factors, and S&C input and physical performance is only part of the overall picture. Gym performance and improvements in physical capabilities are only a part of the bigger picture. As S&C practitioners, we are tasked with improving physical capabilities; the assessment of actual performance should be performed by the sports coach.

Practical applications

The present study sought to conduct a comprehensive survey of strength and conditioning testing and monitoring practices in senior professional male football. The results of this survey should act as a resource for current and upcoming practitioners at all levels, to understand and assess their own and others testing and monitoring practices.

The original findings in this research are that practitioners will test and monitor their players to improve performance, prevent injury risk and manage training load. It appears that there is no universally adopted monitoring approach within professional football, although many clubs do adopt similar practices. Although there is a plethora of technology available to be used in professional sport, the majority of practitioners use relatively simple assessments throughout the season. The most frequently used assessments are body composition, training load via GPS data (both 82%), heart rate response (74%), player wellness (72%) and lower limb power via CMJ (59%). Assessment of body composition was the most frequently used test to assess the players during the pre-season period; with body composition and GPS tracking most common during the in-season. However, in-season testing of physical performance such as speed, change of direction and muscular strength were most commonly ‘never’ assessed. In addition, coaches value athlete feedback as the biggest determinant of a successful strength and conditioning programme ahead of any other indicator. However, more detail on what actually constitutes athlete feedback is required.

Physiological or performance assessments may be of little use when considered in isolation. It appears that practitioners use multiple assessments to provide a more comprehensive picture of their athlete's response to training, as highlighted with clubs monitoring 9.7- 9.8 markers during the pre- season and in-season period.

Given that physical performance assessments are used to inform decision-making throughout the player development process, robust interpretation of test performance data is, therefore, paramount. Practitioners in this study do suggest that at least part of their procedures help form meaningful change in their decision-making process, but it is not clear if these practices have been shown to be reliable and valid in giving useful data. Irrespective of how an athlete's response to load is captured, it is crucial to critically appraise the reliability, validity and utility of the data being collected with respect of the context to which it is applied. Depending on resources and context, this may be achieved via 1) existing independent validation; 2) partnering with universities to perform new validation work; or 3) in-house or internal validation work. Any of these methods may help increase practitioner's confidence with a given technology to apply the findings to their club. Understanding which assessment is applicable to your environment and understanding what the data actually means in terms of affecting your decision-making process are important factors when testing and monitoring football players.

Conclusion

This study provides new evidence that practitioners in professional football can use to review current practices and also provide new ideas for diversifying/ modifying future practices. In addition, graduates or S&C coaches wanting to work in professional football may tailor their continued professional development to align with contemporary practices outlined.

In conjunction with previous research into the contemporary practices for S&C provision in football,[6] information obtained from this research will allow coaches access to a serviceable source of the collective ideas of others that they can use to compare with their own provision, and potentially incorporate into their own practices. At this time, no such source of information exists for S&C testing methods in football.

AUTHORS' BIOGRAPHIES

MIKE BEERE, MSC, ASCC

Mike has worked for nine years as a senior S&C coach at Cardiff City Football Club. He has a masters in S&C and is currently studying for a PhD in the 'Practical application of S&C in elite football'.

IAN JEFFREYS, PHD, ASCC, CSCS*D, RSCC*E, FUKSCA, FNSCA

Professor Ian Jeffreys is a coach, author and educator who is currently the academic director of Setanta College in Ireland. A former professional rugby player, he is the author of ten books, a former board member and vice chair of the UKSCA, and a former board member and vice president of the NSCA. He is a fellow of both organisations and the Editor of *Professional Strength and Conditioning*

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Part C of project one details the questions and responses from the survey into S&C practices that was administered for the published articles in Part A and Part B.
The same 51 practitioners' responded to these questions, and as such their details do not need further mentioning in this chapter.

The final section of the survey allowed football S&C coaches the opportunity to provide additional data or make specific comments regarding S&C practices, S&C literature, injury rates, and the future of S&C in football.

Opinions on current research and ideas of best-practice

In this section, coaches were able to give their opinions and experiences regarding current published S&C and medical research, and ideas of best-practice.
Results show that 32 (62%) coaches feel that too much research is clinically based and not always applicable to the real world situation. Twenty-four (49%) coaches say that they are aware of the evidence based research, but factors outside of our control do not allow us to implement what we desire, 17 (33%) say there is not enough research published using the level of athletes we work with and there is not currently enough practical day-to-day research being published. Twenty-three (45%) coaches say there is now new practical based research being published that is helping inform our daily practice, but 13 (25%) say that pressure returning players from injury quicker than recommended means we cannot fully follow guidelines of best practice.

McCall et al., (2015) has recently suggested that researchers and practitioners' at the elite level should work together to ensure that future research is directly applicable to the real-world.

In recent times, more long-term, elite football, practical based research regarding injury prevention (Owen et al., 2013; McCall et al., 2014; McCall et al., 2015), fatigue monitoring (Thorpe et al., 2016), return to play criteria (Taberner & Cohen, 2017) and training load (Malone et al., 2015) are becoming available to practitioners'. The results of this current survey would be suggested that more research in line with these studies are needed to help bridge the gap from academic research to practical day-to-day application. With this in mind, these real-world examples of research could potentially help practitioners' deliver a higher quality program of performance enhancement and injury prevention. A review by Drust (2019), suggests that evaluations of the current strategies within football, would not only help current practice, but also have the potential to identify future developments of S&C and sport science provision in football. Drust (2019) continues to state that "*little focus is therefore given to the translation of research findings into either the development of the "real-world" strategies or approaches to the implementation of applied football science protocols into professional organisations*" (pp. 4). As a consequence, in professional football environments, some practices come from practitioner experience and their subjective frameworks of what works in the real world rather than research evidence. Results from this survey have shown that coaches follow the recommended advice given in the literature when they feel it can be applied to their organisation, as shown with 49% of coaches use of eccentric exercises, such as Nordics. It can therefore be suggested that for a greater uptake of research driven practices, S&C research needs to highlight how procedures can be implemented into a day-to-day environment to suit the needs of the coaches. Of note, it could be of importance to provide practical based examples of relationship building and communication skills applicable to the

S&C domain as many coaches believe this to be of greater importance than the exercise prescription (see Project 1b).

Injury occurrence and opinions why

In this section, practitioners' answered questions regarding injury occurrence at their club over the last two full seasons, and were asked for their opinions on why they may still be occurring at a high level despite the increase in evidence-based research into injury prevention strategies. Ranked weighted order (weighted average) responses show that the hamstrings are the most commonly injured muscle group in football, with 28 out of the 51 responders ranking as their most common injury in the past 2 seasons. Table 5 details the ranking of responses to the soft tissue injury rates in football.

Table 1. Soft tissue injury rates in football over the past 2 full seasons in surveyed clubs.

	Rank						
Injured muscle	1	2	3	4	5	6	Weighted rank score
Hamstring	28	10	6	5	0	1	1
Groin	12	13	11	12	0	2	2
Calves	8	12	12	10	4	4	3
Quadriceps	1	9	15	14	8	3	4
Lower back	0	6	6	6	18	14	5
Gluteal	1	0	0	3	20	26	6

Injuries can be a frequent burden within football. Whether it be in the form of preventive measures or guiding a player through rehabilitation, injury management is having a growing impact in the S&C job role. Ekstrand et al., (2020) revealed that while injury incidence in elite football fell during the 18 year period from 2001-2019, the rate of muscle injuries remained constant. In addition, severe injuries remain high and appear to be unaffected by traditional preventative measures for elite teams playing in the UEFA Champions League (Ekstrand et al., 2013). Preventative actions aiming at player factors might not be enough on the professional level, and external factors such as training load, playing style and continuity of club staff should be considered.

In this current survey, hamstring injuries were reported as the most common lower limb soft tissue injury during the past 2 full seasons (2017/18 and 2018/19). Twenty-eight of the 51 responders reported that hamstring injuries were the number one occurring injury, with an additional 10 stating it was the second most common injury within their organisation. These findings are in agreement with those often reported in the literature (Bahr et al., 2015). In addition, the Football Association (FA) injury audit for the 2018-19 season stated that posterior thigh (hamstring) injuries accounted for 16.9% and 16.4% of match and training injuries respectively, making them the most frequent soft tissue injury. Hamstring injuries in both match and training also resulted in the greatest loss of time during the 2018/19 season (FA injury Audit). Results from the current survey also highlight that groin related injuries were ranked as the second most common injury during the past 2 full seasons, with calves as the third. In the FA injury audit 2018-19, hip & groin injuries accounted for 8.4% and 13.1% of match and training injuries respectively, and lower leg (calves) accounted for 12.8% and 12.2%. However, in the FA injury audit, only 18 clubs were included in the report, compared to the 51 in this research. As seen with the FA injury audit, there is a higher percentage of soft tissue injuries in training than there is in matches. Does this mean that we are trying to push the boundaries in training to meet game-play demands, but are getting it wrong?

It has been reported that the majority of hamstring muscle strain-type injuries occur while the athlete is running at maximal or close to maximal speeds (Askling et al., 2007). It has been shown that high speed running volume and sprint distances have increased substantially year on year in Premier league football (Barnes et al., 2014; Bradley et al., 2015). In the recent UEFA Champions League 2018-19 review, average number of sprints per match were as high as 62.25, and metres covered per minute were 137.3. It has also been shown that increases in high-speed running and sprint volume have increased the risk of associated injuries (Malone et al., 2018). It is therefore unsurprising that running was the most common activity leading to match and training injuries in the FA injury audit 2018-19. In this current research, 73% of practitioners' believe that the increase in match play intensity and high-intensity actions may leave players at greater risk of injury, and 47% suggest the increase in our training day high-intensity actions may make the players more at risk of injury. However, it has been shown that athletes who sprint at high intensity (>95% of maximal velocity) during sport practice showed a lower risk of lower limb injuries than those who produced lower maximal velocity (<85%) (Malone et al., 2017). It is therefore important to balance the overall intensity and volume of training to make sure players are being trained adequately and safely. Training load (TL) and increases in hamstring strength are frequently reported markers of injury prevention (Malone et al., 2018; Buckthorpe et al., 2018). If S&C practitioners' could aim to increase the work capacity of players and balance the overall TL, this may help reduce the risk of injury as well as improving performance as seen in other sports (Malone, et al., 2018).

When asked why hamstring injuries continue to rise, one of the respondents in this survey responded "*a lack of focus on running or sprint mechanics*" (participant 25) maybe be a contributing factor to injury risk. An increased efficiency of movement reduces the associated energy cost, that may reduce the risk of injury when a player becomes fatigued during the later stages of a game or across the season.

The increase of in-season and off-season fixture demand has been reported as a potential reason for increased injury rates (McCall et al., 2015) and the findings of this survey shows that practitioners' agree. Thirty-three respondents suggest that the increase of in-season fixtures, and seventeen respondents suggest an increase in off-season fixtures are a cause of increased injury risk. Bengtsson et al., (2013) showed that total injury rates and muscle injury rates were increased in matches with short recovery and that high fixture congestion was associated with increased muscle injury rate in matches in the same period. Unfortunately, there is little that practitioners' can do regarding fixture congestion, other than try to reduce the risk and manage accordingly. Other responses include: it's not always feasible to include these evidence based preventive measures into our training programme (n=14, 27%); training structure is controlled by the management and time available for evidence based practice isn't always available (n=13, 25%); *we include a better programme than those recommended in the literature;* and *literature isn't always correct, despite being statistically significant* (participant 7); and "non-modifiable risk factors, such as age and injury history" all play a role in the increased level of hamstring related injuries.

Researchers and practitioners' alike should be questioning how do we reduce this risk? Is it via strength training, running mechanics, or better quality control of HSR or sprint actions in training? Or a combination of a multitude of factors? Therefore, without an equivocal determining factor for high injury rates in professional football, it could be suggested that practitioners' should aim to incorporate a variety of stimuli focussed on strength, imbalances, RFD, sprint training, movement mechanics and overall training load if we are to reduce injury rates.

The future of strength and conditioning

The last question of the survey asked coaches where they saw the future of S&C provision in football in the next 5 – 10 years. Selected responses included, *"soon be a split between S&C and sports science practices*" (participant 16), "*S&C will take a big role in rehabilitation"* (participant 16), *"the increased demands of the game and athletes will improve buy-in"* (participant 9), *"more data driven"* (participant 18), *"more integrated with coaching staff"* (participant 27), *"a need to quantify gym performance in the way GPS quantifies pitch work"* (participant 1), *"more adherence from players who come through the academy pathway"* (participant 22), *"with players becoming fitter, faster, stronger, the role of the S&C coach will become more vital"*(participant 33) *"need to understand that we are part of football performance, not gym performance"* (participant 18), and *"Strength coaches need to understand more than just the gym and getting stronger being the only answer"*(participant 14).

Although not specifically asked, many coaches gave answers relating to salaries and roles within the industry. Selected answers include "*hope that S&C coaches get the same recognition in terms of salary as other medical staff"* (participant 14), *"clubs will recruit staff for less money as they know there is a high demand for these jobs"* (participant 29), *"best practitioners' are leaving the game due to undervalued salaries"* (participant 49), and *“there isn’t the same career support pathways as there is with technical coaching”* (participant 31).

PROJECT 2

ASSESSMENT OF THE RELATIONSHIP BETWEEN STRENGTH TRAINING, TRAINING LOAD AND INJURY RATES IN PROFESSIONAL MALE FOOTBALLERS ACROSS 2 PRE-SEASON PERIODS.

Abstract

Introduction: Injury rates are high and a regular occurrence in professional football. There are many injury prevention strategies that can be employed with the aim of reducing injury rate. Thus, the aims of this non-interventional study were to evaluate relationships between strength training with injury rate and severity during the pre-season phase.

Materials and methods: 20 senior, male professional football players were involved in this study over two consecutive pre-season phases. Data sets were available from the same 20 players during the first PS (2017-2018) and the second PS (2018-2019) who completed the pre-season phases. External training load was assessed from all athletes during training using Global Positioning System (GPS). Non-contact, soft tissue injury incidence, rate and average severity were recorded for both PS phases. All players completed 8 structured lower limb strength training sessions.

Results: There was no statistically difference in any GPS variable (TD, HSR, HMLD, Dur) for the two PS phases. The injury rate for the two PS were 2.8 vs. 1.4 per 1000 h exposure; total severity was 48 vs. 19 days; average severity 9.6 vs. 6.3; and incidence was 5 vs. 3 for the 2017-2018 and 2018-2019 PS, respectively.

Conclusion: Our study showed that PS strength training is associated with reduced NC-ST injury incidence, rate and severity. This association is most likely multifactorial and other factors may influence injury rate. However, when TL was controlled / not different between PS phases, it highlights that increased exposure to ST may help reduced injury rate in professional footballers. Our findings may help S&C practitioners' to better prepare their athletes during PS.

Key words : Injury severity, strength, load, football, pre-season

Introduction

Injuries in football

The physical demands of professional male football are continually increasing (Barnes et al., 2014; Bradley 2015). These increasing and regular demands of match play and training performed during the season makes players susceptible to injury (Arnason et al., 2004). In support of this, Beere & Jeffreys (2020) have shown that top level practitioners' rank an increase in match play intensity and the increased fixture demand as the greatest extrinsic risk factors as to why injury rates remain high and unchanged in football.

Injury rates can range from 8.1 to 34.7 injuries per 1,000 hours of competition exposure (Lopez-Velenciano et al., 2019; Ekstrand et al.,2016). In addition, it is well known that the most common injury occurs in the lower limb (87%) (Hawkins et al., 2001), with practitioners' working in professional football highlighting that the hamstring is the most commonly injured muscle (see Project 1c, page 128). In particular, injuries occur at the muscle – tendon level (4.6 injuries / 1000 hours of exposure) (Hawkins et al., 2001; Lopez-Velenciano et al., 2019), which represents around 40% of total injuries (Hägglund et al., 2013; Ekstrand et al., 2013; Lopez-Velenciano et al., 2019). Muscle-tendon injuries show a high incidence compared to contusions (1.4 per 1000 hrs), other injuries (0.6 per 1000 hrs), joint and ligaments (0.4 per 1000 hrs), bone fractures (0.2 per 1000 hrs) and skin lesions (0.05 per 1000 hrs) (Lopez-Velenciano et al., 2019).

In addition to injury rate, the mean severity (number of days absence from activity due to muscle injuries) of an injury has been shown to be 15.9 days with an injury burden of 43.1 days per 1000 hours of total activity that has been assessed in a cohort of teams participating in UEFA champions league study (Ekstrand et al., 2011). Reporting of average or total severity is often not reported in studies, where even in a recent meta-analysis of injuries in football, reference to severity of injury is non-existence, with only injury rate, location, and type of injury reported (Owoeye et al., 2020). This may be surprising as the most straight forward approach for assessment of the burden of injuries is to count the total number of days lost due to these injuries. The importance of understanding the severity of an injury in terms of days lost is highlighted as it is shown that a Premier League club suffers an average of 1410 days lost (± 554) as a result of 58 injuries (± 16) (Physioroom.com). Injury severity is more commonly reported by classifying injuries into 4 categories; minimal (<3 days), mild (4-7 days), moderate (8-28 days), and severe (>28 days) as previously reported (Fuller et al; 2007).

Overall, the influence of injuries in professional football is significant, with relationships between reduced injury rates and improved team performance (increased average points per game and higher league ranking) being evident (Hägglund et al., 2013). Due to the negative effects that injuries have on team performance (Hägglund et al., 2013), the large financial cost, whereby the average cost of a first-team player in a professional team being injured for 1 month is calculated at around €500,000 (Ekstrand et al., 2013; Eliakim et al., 2020), and long-term player health (Turner et al., 2000), injury prevention strategies are seen as an essential part of sports performance (Fanchini et al., 2020).

With the increase in physical demands of football performance, improving the ability to not only tolerate these demands, but also to enhance performance, can bring significant benefits to a football club.

Causes of injuries

Although the cause of injury is not always known, and can be multi-factorial in cause, there are a number of potential factors that may increase its likelihood. Injuries are often related to non-modifiable and modifiable, and intrinsic and extrinsic factors. Non-modifiable factors include athlete age, sex, and injury history (Parry & Drust, 2006) that cannot be regulated or altered by the practitioner. The modifiable factors that include player training load, warm-up preparation, muscular imbalances and neuromuscular strength deficits (Buckthorpe et al., 2019; Bahr et al., 2005) can all be regulated by the practitioner. In support of this, previous injury, fatigue, muscle imbalance and physical fitness are seen as the greatest intrinsic risk factors for non-contact injuries in elite level football teams (McCall & Carling, 2015; McCall et al., 2015). The relationship of one or multiple factors may lead to increased risk of injury within professional footballers. Reduced recovery time, congested match schedule and match play intensity are frequently supported extrinsic risk factors associated with injury risk in top-level footballers (Bengtsson et al., 2013; Dupont et al., 2010). In support of this, top level practitioners' rank an increase in match play intensity and the increased fixture demand as the greatest extrinsic risk factors as to why injury rates remain unchanged in football (Beere & Jeffreys, 2020)

While there is a multitude of potential factors that contribute to injury occurrence in professional football, this paper will focus on the two of the biggest modifiable risk factors: strength and training load.

Reduced strength, strength asymmetry and a strength ratio imbalance between muscles are key risk factor for muscle injury (McCall et al., 2015; Volpi et al., 2016; Read et al., 2016; Read et al., 2019). Eccentric hamstring strength (<256 N) (Opar et al., 2015) and single leg hamstring bridge (SLHB) scores of less than 20 reps (Freckleton et al., 2011) are associated with increased risk of hamstring strain injury. Decreases in hamstring strength relative to quadriceps strength is a risk factor for knee ligamentous injuries in both male and female youth football players (Volpi et al., 2016; Read et al., 2016). While current evidence is inconclusive for muscle strength asymmetry (i.e., right vs. left limb) as a risk factor, eccentric hamstring strength asymmetry is specifically indicated as a key predictor of injury among male youth football players (McCall et al., 2015).

Current evidence across team sports indicated that load, in terms of player exposure and /or exertion, could either be an independent protective or risk factor for injury, depending on whether load administration is optimal and progressive, or sub-optimal (e.g. load spike), and that this relationship is likely moderated by other risk factors for injury (Gabbett, 2016; Malone et al., 2019; Gabbett et al., 2016; Bowen et al., 2017). Available evidence suggests that avoiding a spike in load (e.g., the acute to chronic workload ratio) is associated with less football injuries (Bowen et al., 2017; Malone et al., 2016).

Therefore, the individual and collective relationship of athlete strength and training load should be examined to determine if injury rates can be affected with appropriate exercise based strategies.

Existing solutions – current literature

Opportunities for intervention: Injury prevention programmes

During recent years, there has been, and continues to be, an influx of published research in the injury prevention domain, including the development of models and framework to guide prevention (van Mechelen et al., 1993; Finch, 2006; Meeuwisse et al., 2007; O’Brien et al., 2018), with many practitioners' looking to this research to guide and enhance their practice (see Project 1c)

Given the increasing use of scientific principles to monitor athletes, research exploring associations among injury, performance and training load has increased. Exercise-based strategies (EBS) are frequently and importantly perceived strategies implemented by elite football teams to prevent muscle injury (Beere & Jeffreys 2020; McCall et al., 2015). Literature often refers to the implementation of "injury prevention exercise programmes" (IPEPs) for their intervention stimulus (O'Brien et al., 2016). Injury prevention exercise programmes (IPEPs) are an inherent part of training in professional sports (Plummer 2019). Providing performance-enhancing benefits in addition to injury prevention may help adjust coaches and athletes' attitude towards implementation of injury prevention into daily routine. *** to note, the terms EBS and IPEP's are one of the same, and could be used interchangeably. In the context of this project, we will refer to any injury prevention strategy as an exercise based strategy, EBS. ***

Recently, Emery & Black, (2019) established that primary prevention of injury may be the *"low hanging fruit",* which may have the greatest impact in reducing the amount of musculoskeletal injuries. In particular, previous research reported a mix of strategies (e.g. strength training, core training, balance) can have a positive effect on performance (Silva et al., 2015) and reduce the risk of injuries in football players. EBS such as the FIFA 11+ (Soligard et al., 2009), the Prevent Injury and Enhance Performance programme (PEP) (Steffen 2008), and Sportsmetrics (Mandelbaum et al., 2005) have been previously designed and proven effective in preventing sports-related injuries. The FIFA 11+ programme has shown to induce a substantial injury-preventing effect by reducing injuries by 39% compared to control protocols (Thorborg et al., 2017). For example, groin injuries have been effectively reduced with implementation of the FIFA 11 + programme. However, other adductor specific protocols using the Copenhagen adductor exercises, have also been shown to be effective in reducing injuries (Haroy et al., 2019; Kohavi et al., 2018).In addition, the PEP and the Sportsmetrics programme are two programmes that have been shown to significantly reduce ACL injury rates and improve athletic performance (Noyes & Westin, 2012). However, these EBS have only been shown to be effective in youth or female athletes, with limited or no evidence suggesting successful practices in elite male football players.

The gold standard approach to optimising high-performance outcome such as injury prevention in professional team sports is considered through the adoption of an "evidence-based practices (EBP) approach (Coutts, 2017). An EBP approach involves a combination of high-quality research (i.e. scientific evidence) and current best practice (i.e. practitioner experience). In support of this, Bishop (2008) suggested that where possible, practitioners' should preferentially adopt strategies to align evidence-based interventions with the demands of professional settings.

How effective are current practices?

Exercise-based strategies are frequently used by professional teams to prevent muscle injuries (McCall et al., 2015; Beere & Jeffreys, 2020). McCall et al., (2015) assessed the scientific evidence underpinning what professional team practitioners' actually prescribe to their players. The most commonly used EBS in professional sport often include eccentric, balance and core exercises (McCall et al., 2014; McCall et al., 2015). However, despite the importance placed on these exercise types and their widespread use in elite football, the actual scientific evidence supporting some of these strategies is weak (McCall et al., 2015).

The largest injury epidemiology study in the world that prospectively follows elite football teams led by the UEFA Football Research Group has shown that while overall injurie rate may be improving, muscle injuries have not reduced over an 18 year period. (Ekstrand et al., 2020). This may call into question the effectiveness of current EBS. Indeed, current preventative exercises may be overly static or consist of very controlled dynamic movements, which may not offer a sufficient stimulus to achieve the desirable preventative effects (Ekstrand et al., 2013). Since a key element of football is 'speed', it could be recommended that injury prevention exercises should be specific to sufficiently meet the high speed match demands of football (Ekstrand et al., 2013).

Success rate of an EBS is often dependant on a number of factors including the training frequency and duration, the sample population, program compliance, programme content, as well as the desired outcome, and as such many EBS have been shown to have differing success rates.

Training frequency

Interventions involved in a number of EBS for reducing injury risk have considerably different programmes, designs, methodologies and principles (Askling et al., 2003; van der Horst et al., 2015; Petersen et al.,2011; Rønnestad et al., 2011; Bogdanis et al., 2011, Owen et al 2013; Zouita et al., 2016). A meta-analysis by Laursen et al. (2018) demonstrated that average volume, average intensity and mean programme duration varied considerable between a number of EBS. For example, Askling et al., (2003), van der Horst et al., (2015), and Petersen et al., (2011) performed directly comparable pre-season hamstring programmes with the aim of preventing acute hamstring injuries in football players. Intensity and duration of the EBS programme was similar, but volumes (based on repetitions per week) differed; ranging from 11.7 to 64 repetitions per week.

The conclusion from this meta-analysis was that strength training intensity and volume per week, but not intervention duration provided a positive effect on injury rate. Ultimately, this can therefore mean that comparing these findings, and applying them to the day to day world of practice challenging. Additionally, when assessing training load, Ekstrand et al., (2020) demonstrated that a greater number of pre-season training sessions resulted in a greater positive effect on in-season injury rate.

Population

Research of EBS effectiveness with elite, male footballers is unequivocal at best.

In fact, a recent systematic review investigated the effectiveness of training interventions to prevent muscle injuries in male elite players, and in contrast to female and youth athletes, found limited scientific evidence to support EBS in preventing muscle injuries (Fanchini et al., 2020). EBS intervention studies involving male youth football players have shown reductions in overall injuries (Emery & Meeuwisse, 2010; Junge et al., 2002; Zouita et al., 2016). Other studies involve female players have also shown a significant preventive effect of the intervention (Heidt et al., 2000; Soligard et al., 2008). Owen et al., (2013) showed that a multifactorial EBS based around strength, balance, core and mobility exercises reduced soft tissue injury occurrence, but didn't reduce overall injury rate in senior male football players across 2 seasons. This however, was suggested to be due to an increase in contusion injuries.

In addition, there appears little knowledge exploring the function of S&C in professional, elite male football, its relevant application and therefore suggested best practices for preventing injury-related risk factors. It is evident from the existing literature that further research is required to investigate the "real world" application of S&C practices in elite, male football players. This is particularly true given the potential positive impact that S&C training programmes can have on both performance and injury prevention, two key facets that players and coaches attempt to achieve within their roles.

Programme compliance

The success of an EBS intervention can be heavily influenced by an athletes participation in the intervention (O'Brien et al., 2017; McCall et al., 2016; Ripley et al., 2021). Results from project 1a (page 87-, Beere & Jeffreys 2020) show that 76% of coaches report that 91-100% of professional football players regularly complete lower limb S&C sessions, with 88% of coaches saying sessions are compulsory for all. Many different definitions of compliance have been reported in the literature (Klugl et al., 2010). In addition, the terms and constructs of compliance and adherence have been used interchangeably to describe the uptake of an intervention programme. However, the two terms are not synonymous. Compliance refers to a participants obedience in a study where a researcher provides the intervention, with little to no right of consultation on behalf of the participants. It can thus be defined as "*the athletes' correct following of the prescribed intervention*" (Verhagen et al., 2011 page 1). Adherence implicates a more collaborative environment in which the researcher / practitioner and study participant cooperate to develop an intervention that fits with the participants' opportunities and restraints (Steffan et al., 2013). Research, ideally performed in a more or less controlled setting, therefore implicitly focuses on compliance, rather than on adherence.

One of the main limiting factors for the effectiveness of preventative programmes is the poor long-term compliance of the players (O'Brien et al., 2017), which may influence the rate of injuries (Bahr, 2015; Van Beijsterveldt et al., 2013), and prevent the effect an EBS interventions may actually have (McCall et al., 2016). The importance of compliance to any EBS has been highlighted by McCall et al., (2016) who revealed that the medical officers within elite European football teams believe player adherence to an injury prevention programme is either 'essential' (53%) or 'very important' (44%) to reduce injury occurrence. Recently, the level of compliance to hamstring injury prevention programmes has been quantified (Ripley et al., 2021). Boundaries of very high (>75.1%), moderate-high (50.1 – 75%), low-moderate (25.1 – 50%) and very low (<25%) have been proposed to categorise level of compliance to a programme. Results showed that with increased compliance and consistency of training, there is a greater effectiveness of the intervention, with a compliance of > 50.1% having a positive effect on hamstring injury incidence. Furthermore, with increased compliance (>75.1%) there is a 139% increase in intervention effectiveness. Soligard et al., (2010) showed a risk of overall and acute injuries were reduced by one third among players with high compliance to a EBS compared to those with intermediate or low compliance. Compliance in this study was reported with a yes/no response if a player completed the programme or not, and as an overall percentage of completed sessions. While the boundaries to determine high, intermediate or low compliance were not mentioned (other than groups being split into tertiles) the players with high compliance completed the EBS more than six times as often as players in the tertile with lowest compliance.

While strong evidence exists to suggest that eccentric hamstring strength training via the Nordic hamstring exercise (NHE) could help reduce hamstring injuries in professional football players (Askling et al., 2003; Petersen et al., 2011; Bourne et al., 2017), this preventative effect is not seen when compliance to the programme is poor (Bahr et al., 2015).

The level of player compliance to the EBS reported varies greatly across elite football team (McCall et al., 2016). Result from McCall (2016) suggest that of the 34 number of teams questioned, only four teams specified having a perfect compliance from all players, while six stated having a perfect compliance from around 50-80% of players and seven teams had perfect compliance from less than 50% of their squad. However, 17 teams also stated that they had either low or no adherence in up to 50% of their squads. From personal experience, "perfect" compliance to any programme is very hard to achieve, and thus questions perfect compliance report in this research. Perfect compliance would suggest that every player completed every session as per the programme prescription, with no changes or modifications. Individual changes to a programme are, in this practitioners' experience and opinion, a natural occurrence in professional football, and should not be seen as a negative on programme compliance. Furthermore, it is suggested that both player (Bahr, 2015) and coach compliance (McCall et al., 2015) to an EBS may not be adequately reported, and as such the ability to understand the effectiveness of any intervention strategy may be limited. In addition it can be challenging to understand the effectiveness of EBS research due to inconsistent or incomplete reporting of rates of player compliance (Emery et al., 2010; Gilchrist et al., 2008; Soligard et al., 2008, Hägglund et al., 2013). Finally, it is often unclear whether reported compliance rates are based on a team or individual player level. When injury prevention measures are embedded into team training sessions, the compliance of the team is likely to depend greatly on the motivation, choices and actions of the head coach (Soligard et al., 2010). Recording individual participation, on the other hand, reveals the rate of uptake and actual usage of the intervention for each player. It has therefore been suggested that reporting group and individual rates are essential since the overall compliance is the product of the team completion and player attendance rates (Sugimoto et al., 2012; Soligard et al., 2010).

The variation in results of EBS could also be due to the high level of individualisation from practitioners' when prescribing the programme. The injury prevention practices among elite adult football teams has been surveyed and examined (McCall et al.,2015a; McCall et al., 2015b; O'Brien & Finch, 2016). These studies have shown that despite practitioners' following a coherent approach, a number of the practices implemented are not well supported by research evidence (McCall, Carling, et al., 2015; McCall, Davison et al., 2015; O'Brien & Finch, 2016). This is also shown to be the case in elite football academies (Read & Lloyd, 2018). O'Brien et al., (2017) showed that delivery of the FIFA 11+ injury prevention programme in UK football academies varies depending on facility availability, exercise selection, exercise load and number of practitioners' available. In support of this, Beere et al., (2020) (Project 1a) highlighted that poor facilities, and lack of staff are substantial barriers to successful S&C practice in elite football. Taken together, these studies represent football in the specific context of professional clubs where the training programmes, logistical demands and available facilities potentially differ to those utilised in recommended research.

Programme content

Complete and explicit reporting of the component of an EBS in research is important for the interpretation and implementation into practice. However, many EBS interventions are often incompletely described in study reports (Simera et al., 2010). The Consensus on Exercise Reporting Template (CERT) was developed to provide direction for reporting exercise interventions (Slade et al., 2014; Slade et al., 2016). It is aimed to provide guidance on a minimum a set of key items considered essential to report replicable exercise programmes. It can be suggested that these items should be reported in all studies irrespective of exercise type or targeted cohort. Precise information about the type of exercise, as well as details such as its dosage, intensity and frequency, and whether or not it requires supervision or individualisation, are required to fully understand the intervention and how to replicate it (Smidt et al., 2005).

Intervention programmes targeting individual risk factors for specific injuries have achieved significant results. For example, eccentric strength training has been shown to reduce hamstring injury risk in football players (Askling et al., 2003; Petersen et al., 2011; Bourne et al., 2017) and ACL risk can be reduced with strength training in youth football players. (Hägglund et al., 2013). However, whilst intervention programmes focussing on specific injuries are well supported and researched, the nature of professional sport requires more generic (non-specific) preventive EBS to reduce the risk of incidence of all injuries that are most common in football, as well as aim to improve athletic performance. As such, many EBS often contain a multitude of exercise modalities such as strength, balance, core and stretching. Results of recent meta-analyses investigating the effectiveness of EBS used in football, show that EBS that programmed a combination of strength, balance, core and plyometric exercises were effective in reducing the rate of lower extremity injury (Crossley et al., 2020; Brunner et al., 2019). However, promoting a multifactorial EBS can make it difficult to identify which element of the programme results in the intervention being deemed successful. Junge et al., (2002) showed a reduction in injury rates in youth football players who completed an EBS. However, the EBS was part of other preventative measures such as taping, rehabilitation and promotion of fair play. Likewise, although reducing injury risk, Söderman et al.,(2000) and Emery et al., (2010) primarily focussed on balance training, whilst Heidt (2000), Soligard (2008) and Steffan (2008) focussed on several aspects such as core stability, balance and strength in their EBS. In a comprehensive 2-season long study, Owen et al., (2013) showed that a multifactorial EBS based around strength, balance, core and mobility exercises significantly reduced soft tissue injury occurrence, yet it didn't help reduce overall injury rate.

The best solution?

Among all EBS traditionally proposed in research to reduce lower limb injuries, strength training has consistently shown to have the greatest benefit in reducing acute and over use lower limb injuries (Cronstrom et al., 2016; Freckleton & Pizzari, 2013; McCall et al, 2015, Brunner et al., 2019, Bahr, Thorborg & Ekstrand, 2015, Lauersen et al., 2014) with a positive dose-response relationship between strength training and injury prevention being previously reported (Lauersen et al., 2018). A recent meta-analysis (Brunner et al., 2019) showed that ten of the eleven programmes analysed which comprised mainly of strength training were shown to be effective in reducing overall injury rate, concluding that lower limb strength training exercises should be prioritised in EBS to reduce the risk of injury. Well-developed lower-body strength has also been shown to be associated with a greater tolerance to higher workloads as well as a reduced risk of injury in team-sport players (Malone et al., 2018). This may be due to the fact that strength training promotes a better neuromuscular function of the involved musculature, improving coordination, strengthening of the adjacent tissues reducing critical joint loading, and increasing the psychological perception of high risk situations (Lauersen et al., 2018).

Collectively, results indicate that EBS which include strength exercises are highly effective at reducing overall injuries, as well as specific injuries such as anterior cruciate ligament

(Hägglund et al., 2013) and hamstring injuries (Askling et al., 2003; Petersen et al., 2011; Bourne et al., 2017). Previous studies in professional football (Owen et al., 2013; Junge et al., 2002) have shown that an EBS intervention can have the greatest effect on reducing mild (4 – 7 days) injuries, but do not mention total or average number of days actually lost to injuries.

The inclusion of strength training in this research

Despite most studies utilizing strength exercises to successfully promote the reduction in injury incidence, it appears that many programmes do not follow basic training principles such as progression in exercise selection, intensity and training volume (Crossley et al., 2020).

Thus, it appears that there is still scope to conduct training interventions using traditional resistance training methods**,** with heavier loads that are targeting specific increases in strength (i.e. >85% 1RM) and some form of periodisation, overload and progression in football players. The EBS programme in this study was specifically designed to help prevent injuries, increase performance by following the principles of training and programme periodisation. Consequently, scientific information and recommendation should be provided to S&C coaches on how to accurately design and prescribe strength training strategies for non-contact injury prevention in football, with practitioners' working in elite male football questioning the amount of research available that is applicable to the real-world environment of professional sport (Beere & Jeffreys, 2020). Ultimately, improving S&C coaches' understanding of why and how sports injuries are prevented may promote uptake of targeted strategies and help S&C coaches fulfil this responsibility with the profession. Where possible, practitioners' should preferentially adopt strategies to align evidence-based interventions with the demands of professional settings (Bishop, 2008).

Training load

Within professional football, it is common place for sport science staff to monitor a range of variables across the training programme (Akenhead and Nassis, 2016; Beere & Jeffreys 2021: Project 1b). The monitoring of training load (TL) on a daily basis is now common practice in order to help facilitate the prescription of correct 'dose' of TL to maximise adaptation and minimise injury risk.

The interest in tracking and monitoring player 'readiness' often leads to the implementation of monitoring strategies that are most commonly reported with a focus to on pitch- based training load. Gross TL is the product of training frequency, volume, and intensity (Borresen & Lambert, 2009). Although there is recent debate surrounding the feasibility and calculation and subsequent value of a work load model for predicting injury incidence (Buchheit et al., 2017; Lolli et al., 2018) it is well appreciated that maintenance of a stable and constant training stimuli helps keep players fit. Current evidence suggests that sudden increases in training volume and / or intensity are associated with increased risk of injury (Colby et al., 2014; Gabbett et al., 2012; Ehrmann et al., 2016).

As well as the aforementioned muscle strength imbalances, overall training load has been proposed as risk factors for future injury (Gabbett et al., 2012; Eliakim et al., 2018) In support of this, Ekstrand et al., (2013) revealed that muscle injuries and severe injuries remain high and appear to be unaffected by traditional preventative measures for elite teams playing in the UEFA Champions League. It was concluded that preventative actions aimed at reducing injury rates might not be enough on the professional level, and external factors such as overall training load, playing style and continuity of club staff should be considered. The interaction between workload, injury and performance is central to managing athletes in team sports (Eirale et al., 2012; Hägglund et al., 2013).

As such, the pitch based training load will also be considered in the analysis of injury rates in during the two pre- season phases in this research.

Definition of training load

Gross or overall training load is the product of training frequency, volume, and intensity (Borresen & Lambert, 2009). Furthermore, training load is typically categorised as external and internal training load (Wallace et al., 2014). External training load can be described as the physical work prescribed and undertaken. External load can be quantified in variety of manners, often with the use of global positioning systems (GPS) tracking. Common GPS derived units measures include total distance covered, high speed running distance (above 5.5m/s), acceleration/ deceleration efforts and estimated metabolic power (Malone et al., 2015; Kalkhoven et al., 2020, Akenhead and Nassis,2016). Conversely, internal training load can be described as the psycho-physiological stress experienced by an athlete. The concept of internal load incorporates all the psycho-physiological responses that an athlete initiates to cope with the requirements elicited by the external load. Common measures are heart rate, blood lactate, and ratings of perceived exertion (RPE) (Malone et al., 2015; Kalkhoven et al., 2020).

GPS metrics

Developments in technology and analytical methods have led to new possibilities in the applied environment. The plethora of variables produced with the GPS has given practitioners the ability to monitor training load in greater detail than ever before. Recently, studies have utilised GPS tracking to analyse activity of football players during training and competition and to deduce information on underlying physical demands using these data sets (Carling et al., 2005; Carling, 2010). Selecting the correct metrics for analysis is considered key to accurately determining the overall training load and concurrent risk of injury in players. These metrics differ in value and applicability regarding injury risk quantification and their capacity to reflect casual pathways to injury (Kalkhoven et al., 2020). Research from professional football shows an increased risk of injury when high-speed running (distance > $5.5 m.s^{-2}$) was higher than normal acute loads and when chronic loads were higher than normal over consecutive weeks (Jaspers et al., 2018). A similar trend was identified by Bowen et al (2017), with high acute and high chronic high-speed running both significantly increasing non-contact injury risk in elite youth football players. The direct link between running load and injury risk is also evident in other sports such as Gaelic football (Malone et al., 2017), Australian football (Colby et al., 2014) and Rugby Union (Gabbett & Ullah, 2012). Additionally, there may be a 'fear' of injury when performing HSR in training leading into a game. In support of this, results highlighted in project 1c (page 124) demonstrate that 73% of S&C coaches in professional football believe the gradual increase in match play intensity and high-intensity running actions may leave the players at greater risk of injury with a further 47% stating there has been an increase in our high-intensity running actions that may make the players more at risk of injury. However, there could be an equally high risk by restricting players from performing HSR during training, where they become underprepared to run at these speeds during match-play (Gabbett et al., 2016), thus highlighting the challenging in balancing the work load intensity during training weeks.

The inclusion of training load assessment in this research

Management of training load has shown to be important for mitigating injury risk in football (Watson et al., 2017; Bowen et al., 2017). Ultimately, understanding and monitoring the training programmes of football players is vital to ensure that the optimal training load is implemented (Piggott, 2009), with the aim of increasing positive performance adaptations and reduce the prevalence of injury (Bowen et al., 2017; Watson et al., 2017; Jaspers et al., 2018). Therefore, one of the key methodological considerations in the current study was to assess the training load variables across the two pre-season phases. It was hypothesized that training load was similar between the two pre-seasons due to the same management and staffing. Thus, controlling this risk factor variable, would allow the practitioners' to establish a greater understanding of the potential effects that strength training may have on injury rate, occurrence and severity.

Pre-Season training phase

Prevention of preseason injury is important to ensure availability of players for the commencement of the season and to decrease the risk of injury later in the season. Balancing the on pitch training load and any gym based strength and conditioning loading during the pre-season phase is a key consideration for any sports science or strength and conditioning practitioner. Pre-season football training aims to develop players' physical and mental capacities and prepares them for the demands of the forthcoming competitive season (Stolen et al., 2005; Ekstrand et al., 2020). This period is characterised by the greatest increase in fitness level, but this improvement may not be sufficient to handle the intensity and stress associated with competitive football, leading to higher risk of injuries (Junge & Dvorak, 2004).

It has been proposed that the pre-season period is the period during a season with the highest training load and subsequent disproportionately high number of training injuries (Hawkins et al., 2001; Jeong et al. 2011, Jones et al., 2017). It has been shown that the pre-season phase has a greater proportion of overuse injuries including tendinopathy (Hawkins et al., 2001). Several reasons for this increased incidence have been suggested, including hard playing surface (Inklaar et al., 1994), high training intensity (Ekstrand & Hilding,1999) sudden change in training intensity from closed season to preseason (Arnason et al., 1996) and short preseason preparation (Engstrom et al., 1990). It has also been stated that an inappropriate pre-season training period, as indicated by lower improvement in aerobic fitness can be associated with a higher incidence of injuries throughout a competitive season (Eliakim et al., 2018). In addition, a greater number of pre-season training sessions are associated with less injury load during the competitive season (Ekstrand et al., 20200). This suggests a possible role for high quality pre- season football training not only for shaping physical fitness, but also, among other factors such as tactical preparation, for injury prevention.

Overall justification for this research

Whether it be in the form of preventive measures or guiding a player through rehabilitation, injury management is having a growing impact in the strength and conditioning (S&C) coaches' job role (Talpey & Siesmaa, 2017; Beere & Jeffreys, 2020). In fact, according to the National Strength and Conditioning Association (NSCA) Strength and Conditioning Professional Standards and Guidelines (2017), S&C coaches have a "*duty to the participants they serve to take reasonable steps to prevent injury, and to act prudently when an injury occurs*", and "*to provide guidance for the athletes in the area of injury prevention*". O'Brien et al., (2016) showed that fitness coaches are the primary deliverer of injury prevention programmes in professional football settings. In addition, Beere & Jeffreys (2020) (project 1 a, page 86) highlight that 48% of practitioners' in elite football are responsible for targeting injury prevention strategies within their S&C sessions.

Ultimately, therefore improving S&C coaches' understanding of why and how sports injuries are prevented may promote uptake of targeted strategies and help S&C coaches fulfil this responsibility with the profession. The S&C coach should not only possess the knowledge and insight to physically prepare athletes for competition, but they are also in the unique position within the multi-disciplinary team to characterise the stress of training (training load) and an athletes response to it. The S&C practitioner should therefore aim to monitor both pitch based training load and injury prevention programming in order to prepare players effectively for competition and reduce risk of injury.

There are several challenges associated with research into professional football. These can include inadequate subject numbers, the exclusion of control groups, and a variety of external variables that may interfere with any planned intervention such as changes in fixture schedule, changes in management, changes in training load, injuries to players acting as subjects, or the transfer of players to another club. The ability to control these variables is difficult and thus provides a challenge when trying to compare intervention based studies in this environment. In this current research, data from two 6 week- pre- season phases from one professional senior, male football team will be compared to assess the impact of a structured lower limb strength training programme effect on non-contact muscle and tendon injury rates. Season 1 (2017-2018) will act as a control, and season 2 (2018-2019) will act as the intervention group. The intervention was added during the second season due to the senior management changing their approach to S&C practices during pre-season phase due to an increase in competition standard. During pre- season 1, the players were training and preparing for a season in the English Championship; and during pre- season 2 the players were training and preparing for a season in the English Premier League after being promoted during the 2017-2018 season. This is unlike previous comparative studies where either the injury prevention programme was removed during the second season (Owen et al., 2013); the intervention has no control group (Zouita et al., 2016); or the intervention was different between groups within the same squad of players (Rønnestad et al., 2011).

As discussed, improved neuromuscular capacity, control, and strength are protective against injuries among football players (McCall et al., 2015; Volpi et al., 2016; Read et al., 2016; Read et al., 2019). Additionally, current evidence suggests that load management as a viable target for mitigating injury risk in football (Bowen et al., 2017). However, to the best of the authors' knowledge, no study compared two preparation periods monitored in the same football club and examined the influence of training load and strength training on injuries in professional football players. Therefore, the aim of the current investigation was two-fold. First, we aimed to assess if training load was similar between the two consecutive pre-season phases. This would allow for a greater, more accurate comparison of the pre-season periods, and the potential effectiveness of strength training on injury rates. A secondary aim of the intervention was to explore the effectiveness of a strength training programme on the total number of injuries and muscle injuries by comparing previous seasons injury data when no strength training was included to a season where strength training was included.

It is hypothesized that the S&C programme used during the intervention pre-season would help reduce the number of non-contact, muscle and tendon injuries when compared with the control pre-season. It is also hypothesized that there be a reduction in the severity of non-contact injuries when comparing the intervention with the control.

Methods

Experimental approach to the Problem

In this study, we aimed to provide an update on the role of strength training in elite, professional male football players and offer new perspectives for promoting strength training as part of an approach to reducing the risk of injuries during the pre- season phase.

The study was conducted over 2 consecutive pre- season phases (2017-2018 and 2018-2019) with one professional football team. The first pre- season (2017- 2018) acted as the control, with the second (2018-2019) as the intervention pre- season. During pre- season 1, the players were training and preparing for a season in the English Championship; and during pre- season 2 the players were training and preparing for a season in the English Premier League after being promoted during the 2017-2018 season.

Prospective data collection of injury rates and training load from the first day of pre- season training until the day prior to the first game of each season were assessed.

During the intervention pre- season, the players performed a structured strength and conditioning programme before the technical and tactical training sessions. A total of 8 lower limb strength training sessions were performed across the pre-season phase. During the S&C sessions, players performed lower limb resistance training suitable to their needs. Sessions were targeted at improving overall strength, movement competency and strength endurance / robustness. Session examples can be seen in table 4. No additional, structured strength training programme was included during the first pre-season 2017-18 phase.

For the purpose of the current study, all the on-field physical, technical and tactical sessions carried out as the first team sessions were considered. This refers to training sessions in which both the starting and non- starting players trained together. Therefore, several types of sessions were excluded from analysis, including individual training, recovery sessions and rehabilitation training. The on-field physical, technical and tactical training content was not in any way influenced by the researchers for the sake of the research design / study. Strength sessions were designed by the researcher, for the purpose of improving football related performance. The researcher, a certified strength and conditioning coach was present in every session to ensure correct execution of each exercise. Data collection for this study was carried out at the football clubs outdoor training pitches and indoor strength and conditioning facility.

Both pre-season periods contained a number of controlled variables. These include: training at the same training facility; the same management, coaches, strength and conditioning professionals and medical staff; the same location and duration of the pre-season training camp away from the main training facility; and the same opposition for 4 of the 6 non-competitive games. In addition the same return to pre-season baseline physical performance assessments were performed (table 2).

The classification of reporting injuries sustained within this investigation follow closely the recommended guidelines proposed by the Orchard, OSIICS classification coding system and has previously been used (Fuller et al., 2006).

Injury information was prospectively recorded, with only injuries obtained during the pre-season phase analysed in this study. The recording period was from the first report day of pre- season up until the day prior to the first competitive match of the season. Any injuries carried over from the previous season or off- season were excluded. Injuries to goalkeepers were also excluded as they performed different on-field training. Injuries were recorded by the clubs qualified medical personal on Benchmark 52.

Assessment of injury rates over the two pre-season phases

The definitions of injuries used within this investigation follow closely the recommended guidelines proposed by International Soccer Injury Consensus Groups (Fuller et al., 2005) and are of similar definitions to those used in other injury-related articles in professional football (Carling et al., 2012; Coppalle et al., 2019).

An injury is defined as**:**

> **"***any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury".* (Fuller et al., 2007, page 329)

Only injuries that are related to football competition or training are recorded. In addition, only injuries obtained during the two pre- season phases were recorded and analysed. The recording period was from the first report day of pre- season up until the day prior to the first competitive match of the season. Any injuries carried over from the previous season or off-season were excluded. The severity of each injury was defined according to "*the number of days that have elapsed from the date of injury to the date of the player's return to full participation in team training and availability for match selection"* (Fuller et al., 2007, page

329). Injury severity was classified into 4 categories; minimal (<3 days), mild (4-7 days), moderate (8-28 days), and severe (>28 days) as previously reported (Fuller et al; 2007), with total and average number of days lost also reported.

Training exposure related to any "*team based and individual physical activities under the control or guidance of the team's coaching or fitness staff that are aimed at maintaining or improving players' football skills or physical condition*" (Fuller et al., 2007, page 329).

The classification of reporting injuries sustained within this investigation follow closely the recommended guidelines proposed by the Orchard, OSIICS classification coding system (Rae & Ordchard 2007). In addition, classification of an injury should be reported by "*location, type, body side, and mechanism of injury (traumatic or overuse) and whether the injury was a recurrence*" (Fuller et al., 2007, page 329. Information of how location and types of injuries should be reported using the OSIICS classification can be found in Table 1 and 2 in the supplementary information section.

Calculation of external load (combined training and match exposure).

The players' physical activity during each training session and match was monitored using portable GPS technology (Viper pod 2, STATSports, Belfast, UK) during both pre- season phases. The device provides position, velocity and distance data at 15 Hz. Each player wore the device inside a custom- made vest supplied by the manufacturer across the upper back between the left and right scapulae. All devices were activated 30 minutes before data collection (start of the session) to allow acquisition of satellite signals as per manufacturer's instructions. After each training session, GPS data were downloaded using the respective software package (Viper PSA software, STATSports) on a personal computer and exported for analysis by a member of the clubs sports science team. Each player wore the same GPS device for each training session to avoid any variability that can occur (Malone et al., 2014). Numerous variables are now available with commercial GPS devices, including acceleration and deceleration efforts and the estimation of metabolic power (Malone et al., 2015). The following variables were selected for analysis in this investigation: training duration, total distance covered, high metabolic load distance (HMLD) and high speed running distance (HSR, distance covered above 5.5m/s) which are commonly reported variables in practice and research (Enright et al., 2020), HSR distance is often monitored in practice and in research due an increased risk of injury when high-speed running was higher than normal acute and chronic loads (Jaspers et al., 2018; Bowen et al., 2017).

Training load data was only assessed for players who completed both pre- season phases. Individual data was collected, and data is presented as a whole squad average and standard deviation.

Subjects

A total of 27 players from one professional male football team completed the full 6 week pre-season training in season 1 (2017-2018), and 27 in season 2 (2018-2019). Goalkeepers were excluded from injury analysis as they performed different physical training to the outfield players, although they did complete the strength training programme. Therefore, 23 players completed pre-season 1; 24 completed pre-season 2, with a total of 20 completing both pre-season periods. Subject characteristics are broken down for comparison and are displayed in table 1.

Table 1. Subject characteristics (mean ± standard deviation) across both pre-season periods

	2017-2018	**2018-2019**
Subject numbers	20	20
Age	25.91 ± 2.7	26.91 ± 2.7
Height (cm)	183.42 ± 5.7	183.38 ± 6.5
Weight (kg)	83.65 ± 7.2	84.25 ± 6.8
Skinfold (sum of 7 sites, mm)	54.62 ± 6.9	53.57 ± 9.7
Body Fat (percentage, %)	9.73 ± 1.4	9.46 ± 1.6

Table 2. Comparison of return to pre-season baseline physical testing scores.

	2017-2018	**2018-2019**	**Level of sig. (p=0.05)**
Squat Jump (jump height, cm)	39.96 ± 5.53	39.37 ± 4.82	0.379
CMJ (jump height, cm)	41.34 ± 5.83	41.51 ± 6.01	0.706
SL CMJ (D) (jump height, cm)	23.96 ± 4.09	23.88 ± 3.84	0.392
SL CMJ (ND) (jump height, cm)	23.76 ± 3.96	23.76 ± 3.42	1.0
SL hamstring bridge MCT (D) (number of reps)	44 ±17	45 ±16	0.331
SL hamstring bridge MCT (ND) (number of reps)	44 ± 15	44 ± 16	1.0
SL box squat MCT (D) (number of reps)	35 ± 9	37 ± 6	0.83
SL box squat MCT (ND) (number of reps)	35 ± 8	36 ± 7	0.331
SL calf raise MCT (D) (number of reps)	34 ± 8	36 ± 7	0.02
SL calf raise MCT (ND) (number of reps)	33 ± 7	33 ± 5	1.0

Note: *CMJ = countermovement jump; SL = single leg; D = dominant kicking limb; ND= non-dominant kicking limb; MCT = muscle capacity test.* Subject n = 20.

Baseline data was recorded the day prior to the first S&C session during the return to pre-season testing to assess muscle function and aerobic capacity Comparisons of results between the two pre-seasons can be seen in table 2. Individual muscle capacity test (MCT) scores for single leg box squats (SLBS), single leg calf raises (SLCR) and single leg hamstring bridge (SLHB) were used to help programme strength sessions during the pre-season and in-season phases. For detailed description of the testing protocols see supplementary section

Pre- Season training phase

During pre- season 1, the players were training and preparing for a season in the English Championship; and during pre- season 2 the players were training and preparing for a season in the English Premier League. Table 3 illustrates the structure of the two pre-season phases, highlighting the number of training sessions and non-competitive fixtures that occurred. During 2017/18 pre-season a total of 24 training sessions were completed, in comparison to 25 during the 2018/19 pre-season. There was a total of 6 non-competitive fixtures during each pre-season, with the same opposition being played in 2017/18 and 2018/19 in 4 of the 6 non-competitive games.

During the two pre- season training periods, players trained five to six days a week, including non-competitive matches (see table 3). The physical training programmes included mainly aerobic and mixed aerobic- anaerobic type activities, with and without the ball, as well as speed and agility training. In addition, training involved technical drills and team tactics and included one to three non-competitive matches per week. Each training session lasted 2-3 hours. The only structured difference between the two pre-season periods was the inclusion of lower limb strength training during 2018/19. Training volume and intensity of both pitch-based and strength training was increased gradually over the weeks in an attempt to avoid overtraining, accumulated fatigue and injuries within the players.

The study was conducted by the sport science and medical department at Cardiff City Football Club after approval by the ethics committee of the University of South Wales. Each subject provided informed consent in accordance with the Helsinki Declaration. To ensure team and player confidentiality, all injury data were anonymized.

Table 3. Pre-season training and fixture schedule, 2017-2018 & 2018-2019

		Day of the week						
Week	P/S	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
1	17-18					Tr	Tr	
	18-19					Tr + S&C	Tr	
2	17-18		Tr	Tr	Tr	Tr	Tr	
	18-19		Tr + S&C	Tr	Tr + S&C	Tr	Tr	
3	17-18		Tr	Tr	Tr	Tr	Tr	NCG
	18-19		Tr + NCG	Tr	Tr + NCG	Tr + S&C	Tr	NCG
4	17-18		Tr + NCG	Tr	Tr + NCG	Tr	Tr + NCG	
	18-19		Tr + S&C	Tr + S&C	Tr + NCG	Tr	Tr	NCG
5	17-18		Tr	NCG	Tr	Tr	NCG	
	18-19		Tr + S&C	Tr		Tr	Tr	NCG
6	17-18		Tr	Tr		Tr	Tr	CG
	18-19		Tr	Tr + S&C		Tr	Tr	CG

Note. *P/S = pre-season; T= training session; S&C = lower limb strength and conditioning session; NCG = Non-competitive game; CG = Competitive game. Total number of training sessions 2017/18 vs 2018/19 =24 vs 25; Total number of NCG 2017/18 vs 2018/19 = 6 vs 6.*

Strength training programme, 2018/19 pre-season

Prior to the start of each pre-season phase, all players were expected to complete an off-season training programme . Each player was given a training programme that they were expected to complete during 4 of the 6 weeks off-season period, with the first 2 weeks advised as complete rest and recovery post competitive season. This programme comprised of physical conditioning (e.g. running based sessions) and upper and lower limb strength sessions. Both components were similar between both periods, with some individual variation accounted for. However, although players were expected to complete the off-season programme that was provided, it would be naïve to assume that every player followed their programme with 100% compliance. It is understood that players may have performed more or less of the programme, and included additional work such as swimming, boxing, bike rides and / or playing tennis. In addition, some players played additional competitive fixtures for their international sides during this period. The strength training during the off-season period aligned itself to be a familiarisation phase for the players. In addition, all players in pre-season 2018/19 had been involved in the strength training sessions during the previous season. Combined, this allowed the S&C practitioner to be confident in the players competency in the majority of exercises that were to be performed during the subsequent pre-season phase. However, the first strength session of pre-season 2018/19 comprised of relatively low load and intensity (70-80% of repetition maximum, 2 x 8 reps). This allowed for the reinforcement of correct technique and form, and adaption to load.

Upon return to pre-season training after the off-season, players physical capabilities were assessed with a number of physical tests (see table 2). Comparison of the physical testing scores showed that there was no significant difference between any of the assessments between the two pre-season phases. The outcome of these tests in addition to an understanding of previous strength training experience and competency dictated the exercises selected for the players for the forthcoming strength training programme. An example of the strength training programme that was implemented during pre-season 2018-19 is highlighted in Table 4. Session volume and intensity was periodised and progressed throughout the pre-season period in respect of training volume, proximity to match-play and the adaption of the player to the sessions, with the intention of allowing physical performance to peak for the beginning of the competitive season.

The programme consisted of generic exercises across the group, but included individualised, tailored exercises, training volume and intensity. All sessions were conducted as a group, within the club training facility with all sessions supervised by the same qualified Strength and Conditioning coach. There was a number of generic exercises within all of the players programme. This is because the overall aim of the programme was to reduce the most common injuries typically seen in football (e.g. posterior chain injuries); improve the physical qualities associated with playing football (e.g. maximal strength output; rate of force development); increase overall robustness / durability; and improve fundamental movement qualities/ efficiency across a range of key exercises. However, individual programming was also incorporated for a number of reasons. These include; previous injury history that requires the inclusion as an addition or substitution of certain exercises with the aim of preventing a recurrence or addressing an imbalance; current issues that prevent the ability to perform an exercise (e.g. insufficient ankle mobility preventing correct technique during a back squat but suitable for a trap bar deadlift); addition of an exercise in order to address some physical discrepancies highlighted in the pre-season screening (table 2); and individual training volume based of the players muscle capacity test scores (table 2), allowing all players to work at the same intensity but within individual repetition ranges.

The exercises utilized traditional resistance training equipment, namely free-weight barbell and dumbbell's, with the addition of slide boards for eccentric sliding leg curls, plyometric boxes for jumping exercises, and glute-hamstring machine for isometric hip extension variations. In addition, given that players are required to be proficient at multiple movement patterns in all three planes of direction (Turner & Stewart, 2014), the sessions utilized a combination of both bilateral (e.g. back squat, trap bar deadlifts) and unilateral (rear foot elevated split squats, step ups) strength exercises. These suggestions are supported from recent empirical research comparing bilateral vs. unilateral training interventions in elite academy football players (Stern et al., 2020). In conjunction with traditional resistance exercises, the sessions also included eccentric bias exercises (e.g. sliding leg curl), isometric holds (e.g. Copenhagen adductor holds), and higher volume body weight exercises (e.g. SLHB, SLCR).

Players only performed strength training sessions at the training ground, under the supervisor of the S&C coach. Players did not perform any additional exercises away from the facility, e.g. at home, during this period. Attendance of the players to the supervised, group strength training session was recorded to report and understand overall compliance. In total 76% compliance (players completed 121 out of 160 sessions) was seen across the sessions during pre-season. Compliance was reduced when players reported but had slight modifications in their programme due to individual concerns such as fatigue or soreness.

Table 4. Example of generic exercises included in week 1 and week 4 S&C sessions

Exercise	Session 1 Sets	Reps	Intensity	Session 4 Sets	Reps	Intensity
TBD	2	8	70 -80%	3-4	6	80% +
BB RDL	2	8	70 -80%	3-4	6	80% +
BB hip-thrust	2	8	70 -80%	3	6	80% +
RFESS	2	8 e/l	70 -80%	3	6 e/l	80% +
Sliding leg curl	2	8		2-3		
Copenhagen Adductor holds	2	2 * 10 sec holds e/l		2-3	4 * 15 sec holds e/l	
SLHB	2		50% MCT	2		75 % MCT
SLCR	2		50% MCT	2		75 % MCT

Note: *TBD = trap bar deadlift; BB = barbell; RDL = Romanian deadlift; RFESS = rear foot elevated split squat; SLHB = single leg hamstring bridge; SLCR = single leg calf raises; MCT =individual muscle capacity test score.* Intensity was self-selected as no RM testing occurred.

Statistical Analysis

Results are expressed as means and standard deviations (SD) unless otherwise stated. The statistical analyses were performed using Statistical Package for Social Sciences for Windows version 26 (SPSS Inc. Chicago, IL, USA).

An independent samples T-Test was conducted to compare injury severity (average number of days lost) in pre-season 1 and pre-season 2. A paired samples T-Test was also conducted to examine the difference between each external load variable as measured with GPS; total distance covered; high speed running distance; high metabolic load distance; and duration between pre-season 1 and pre-season 2. The level of statistical significance was set at $p < 0.05$

Results

Injury rate analysis

A total of 10 injuries were recorded across the 2 pre-season phases (6 during 2017-18; 4 during 2018-19) for the 20 players who completed both pre-season phases.. For the purposes of the final analyses, only those incidences recorded as non-contact, muscle or tendon injuries that resulted in any time loss absence from training were included. As such, there were a total of 8 injuries, with 5 injuries recorded during the 2017-18 pre-season, with 3 injuries recorded during the 2018-19 pre-season.

An independent samples T-Test was conducted to compare injury severity (average number of days lost) in pre-season 1 and pre-season 2. A non-significant difference in days lost was observed between preseason 1 (*M= 9.6, SD = 9.6*) and preseason 2 (*M = 6.3, SD = 3.7; t (5.5)= 0.676, P= >0.05*). When comparing the pre-season phases, total incidence of non-contact muscle and tendon injury was reduced during the 2018-19 intervention period (5 vs. 3); injury rate per 1000 hours was halved (2.8 vs. 1.4); and total severity in terms of days lost due to these injuries was reduced by 60.4% (48 vs. 19). See table 5.

Table 5. Incidence, injury rate and severity of non-contact, muscle-tendon injuries during 2017-18 and 2018-19 pre-season period.

	Pre-Season 2017-18	Pre-Season 2018-19
Incidence of muscle & tendon injuries	5	3
Total exposure, hrs (squad average)	29.1	34.6
Injury rate (per 1000 hrs)	2.8	1.4
Severity, total days lost	48	19
Severity, average	9.6	6.3
Minimal injuries	1	1
Mild injuries	2	0
Moderate injuries	2	2
Severe injuries	0	0

Training load analysis

A paired samples T-Test was conducted to examine the difference between each external load variable as measured with GPS; total distance covered; high speed running distance; high metabolic load distance; and duration between pre-season 1 and pre-season 2 (see table 6). There were no significant differences ($P > 0.05$) between the pre- season phases for any training load measure. There was no statistically significant difference observed between season 1 (*M*=11228.5, *SD*=4399.2) and season 2 [*M= 11570.5*, *SD*=4009.6), *t*(19)= -0.259, *P*>0.05) for high speed running distance. There was no statistically significant difference observed between season 1 (*M*= 120527.1, *SD*=30162.8) and season 2 (*M=138697.1*,*SD*=42909.3), *t*(19)= -1.53, *P*>0.05] for total distance covered. There was no statistically significant difference observed between season 1 (*M*=23372, *SD*=6343.2) and season 2 (*M= 25666.8*, *SD*=8634.9), *t*(19)= -1.046, *P*>0.05) for HMLD. There was no statistically significant difference observed between season 1 (*M*=1745.2, *SD*=436.7) and season 2 (*M= 2074.1*, *SD*=659.0), *t*(19)= -1.879 *P*>0.05) for duration. Thus, no differences were evident between the 2 pre-season phases for training load.

Table 6. Indicators of average external (GPS data) training load of playing squad determined through the pre-season phase of 2017-2018 and 2018-2019

	Pre-Season 2017-18	Pre-Season 2018-19
Duration of training(mins)	1745 ± 437	2074 ± 659
Total distance covered (m)	120527 ± 30163	138697 ± 42909
High Speed Running (m)	11228 ± 4399	11571 ± 4010
High Metabolic Load (m)	23372 ± 6343	25667 ± 8635

Discussion

Injuries are accepted as a common occurrence in professional football, and can provide both a performance (Hägglund et al., 2013) and financial (Ekstrand et al., 2013; Eliakim et al., 2020) burden on teams. It has been suggested that an average English Premier League team can lose approximately £45million per season due to injury related decrements in performance (Eliakim et al., 2020). This is based on estimation of a team's underachievement due to absent injured players, and as a direct calculation of salaries being paid to those injured players (Eliakim et al., 2020). Many factors may contribute to the increased risk of injury (Parry & Drust, 2016; Buckthorpe, 2019), but muscular strength and training load are frequently reported as key determinants (McCall et al., 2015; Gabbett et al., 2016). However, although injuries maybe an accepted occurrence in professional sport, it does not negate the fact that S&C and medical practitioners' are often tasked with, and judged by their ability to reduce the injury risk in their athletes (O'Brein et al., 2017). In fact, preventing injuries is one of the key purposes for implementing strength training in professional footballers (Beere, Jeffreys & Lewis, 2020).

Therefore, the purpose of this investigation was to provide new perspectives for promoting strength training for prevention of injuries during the pre-season phase in professional football players.

Overall findings

In the current investigation, we examined the effectiveness of a structured strength training programme on the total number (incidence), severity and injury rate of non-contact muscle and tendon injuries within an elite professional football club during two consecutive pre-season phases. The study determined if the inclusion of strength training during the 2nd pre-season had a positive effect on reducing injuries.

The primary findings show that the strength training intervention during the 2nd pre-season resulted in:

- no statistically meaningful impact on the average severity (average number of days lost) of injury (M = 9.6 vs. 6.3, p = >0.05);

- a reduction in the total incidence (5 vs. 3) of non-contact, muscle and tendon injuries;
- a 50% reduction in injury rate (2.8 vs. 1.4 per 1000 hours);
- a 60% reduction in total severity (48 vs. 19 days lost).

As previously mentioned, there are many factors such as player's age, fitness level, training load, strength, professional level, and previous injury that may all affect a footballers injury risk. Therefore substantiating a direct causality between strength training and injury risk in the professional sporting environment is challenging. However, a key and novel methodological consideration in this investigation was the additional assessment of training load, and the inclusion of the same 20 players in both pre-season groups. In addition, the outcome of the return to training baseline physical fitness assessments (table 2) highlight there was no significant difference between the two pre-season phases. As mentioned, fitness level and strength (although it could be argued that the muscle capacity tests are a reflection of muscle endurance, not strength*)* are one of a number of factors that may influence injury risk. Therefore, as baseline physical performance was not significantly different, this could further enhance the notion that the strength training intervention had a great influence on the reductions in injury rate, incidence and severity seen.

To help determine if any change in injury incidence, severity and rate was due to the inclusion of strength training, we also assessed external training load during the two pre-season phases. The results suggest that the training load exposure was deemed to be similar, and not statistically different between the two pre-season phases (table 6). This is a crucial finding, as it controls one of the key associated factors with injury risk, and gives support to the effectiveness of strength training as a potential moderator of injury reduction. This is the first study (to the author's knowledge), that can provide a comparison of the overall training load during two pre-season phases (total distance, high speed running, high metabolic load, and total duration) whereby no statistical significant difference was seen. This allowed the comparison of a naturally occurring control and intervention group that is rare in professional sport.

This could be of importance to the practitioner as it provides a greater understanding of the benefit of pre-season strength training on pre-season injury rates that may inform sports teams' planning and preparation.

Injury rate, occurrence and severity

Pre-season training is designed to develop players' physical capacities and prepare them for the various demands of the competitive season (Ekstrand et al., 2020). Injury rate (severity and occurrence) is often less in pre-season than the in-season phase, but the pre-season phase can be characterised by a greater amount of overuse and training related injuries (Hawkins et al., 2001). This may be due to the difference in training vs. competitive match play between the two phases, with a higher match injury rate (9.4 per 1000 hrs) compared with injuries sustained during training (4.7 per 1000 hrs) (Eliakim 2018) in-season. This can be attributed to a number of factors including the higher physical demands on players during matches, the number of contacts and collisions and the fatigue generated during the course of a match (Hägglund et al., 2013; Rahnama et al., 2002). However, it has been demonstrated that there is a greater proportion of over-use injuries (e.g. tendinopathy) during the pre-season phase compared to the in-season (10.2% vs. 5.8%) (Hawkins et al., 2001) with approximately 17% of overall injuries occurring during the pre-season (Woods et al., 2002). This shows that despite the lower rate of overall injuries, potentially due to the far shorter period of training and reduced competitive match play, injury occurrence is still a concern during the pre-season phase in professional football.

Comparison of injury rates in the current study to previous research in elite male professional football is difficult, as the reporting of injury rate and study duration can vary greatly across studies. In this study, injury rate was 2.8 and 1.4 per 1,000 hours of exposure for pre-season 2017-2018 and 2018-2019 respectively. Most studies report injuries that occur over a full season and often include incidence of all injuries. For example, Bowen et al., (2017) showed that total injury incidence was 12.1 per 1,000 hours in professional footballers. This is considerably higher than those reported in the current study due to the large prevalence of contact injuries during the competitive phase. Muscle and tendon injuries have been shown to have a high incidence compared to other types of injuries. Lopez-Valenciano et al., (2019) showed that muscle and tendon injuries have an incidence of 4.6 per 1,000 hours in professional football. Again, these results represent injury rate across a full season. Owen et al., (2013) showed a 43% reduction in soft tissue injury rates during a season that included a multifactorial injury prevention programme aimed at reducing injury rate, compared to the previous season that didn't. However, total injury rate was reported to increase by 9%, as a result of an increase in contusion injuries as a result of match play. In the pre-season phase specifically, Coppelle et al., (2019) showed that over 2 pre-season phases, injury rate was 1.76 and 1.07 per 1,000 hours in elite youth players, with these results showing a greater comparison to the results in our current study.

Although direct comparisons should be avoided, the results of the present study do partially agree with Junge et al., (2002) and Owen et al., (2013) where the training intervention programme elicited the greatest effect on mild and moderate injuries. During the 2nd pre-season phase, there was a reduction in mild injuries (those between 4 – 7 days), from 2 to zero; while there was a reduction in the severity of moderate injuries (8 – 28 days), from 35 days lost to 17, but with no change in injury incidence, 2 vs. 2. Severity (number of days lost) is not often reported in football. Not reporting severity of injuries may miss part of the picture when understanding injury risk and how to plan accordingly. Fortunately, although injuries do occur in footballers and indeed in those in our study, the majority of these injuries are of minimal (1-3 days lost), mild (4 – 7 days lost) or moderate (8 - 28 days lost). This is in agreement with results from a recent meta-analysis in professional football (Lopez-Valenciano et al., 2019). Our results showed that there was no significant difference in the average severity of injuries between the two pre-season phases (9.6 vs. 6.3 days lost). However, the total severity of the injuries was reduced during the 2nd pre-season phase by 60%, with a reduction from a total of 48 days lost, to just 19.

Severe injuries remove players from match-play for lengthy durations, often resulting in significant psychological distress for the athlete (Padaki et al, 2018), and a negative effect on long term team performance (Hägglund et al., 2013). Therefore, if the practitioner can reduce the incidence, or at least the duration of an injury, with a strength training intervention it will be of significant benefit to the club. In addition, it is important that we aim to understand if the severity of injury may share an association with the workload undertaken by football players. Few studies conducted to date have investigated the relationship between overall workload and the severity of injury (Gabbett,2011; Rogalski et al., 2013; Bowen et al., 2019; Bowen et al., 2017). These previous studies have reported the severity of injury in one of 4 categories (minimal, mild, moderate and severe) associated with the number of days missed from training and / or games. However, categorising the injury severity in this way doesn't allow for the use of continuous data that allows researchers to run statistical analyses to study the effect of strength training on injury severity. Therefore, the present study reported the total number, and average number of days missed from training / match play as a result of injury. Using this approach, our results indicate that there was no significant difference in the average severity of injuries between the two pre-season phases (9.6 vs. 6.3 days lost). However, the total severity of the injuries was reduced during the 2nd pre-season phase by 60%, with a reduction from a total of 48 days lost, to just 19.

Training load

Pre-season training is designed to develop players' physical capacities and prepare them for the various demands of the competitive season (Ekstrand et al., 2020). While the main focus of this study was to determine the effect that strength training may have on injury rates, it is impossible to ignore the impact of the combination of concurrent practices that occur in professional football; namely strength training, training load and match play. Therefore, it was deemed important to report the training load during the two pre-season phases to determine any potential effect of the strength training intervention. Results in our study highlighted that there was no significant difference between each of the training load variables; HSR, Time, Total distance and HMLD. This is important to note, as it is clear that a multitude of factors contribute to risk of injury, and training load has often been highlighted as a key contributor to increased risk of injury (Gabbett, 2016) .

There is debate in research and within professional practice as to what constitutes a training load that may increase risk of injury; whether players are at greater risk with a high- or low training load exposure or if high training volumes may provide a protective mechanism against injury (Bowen et al., 2017). This paradox between high and low training loads as a risk factor for injury is demonstrated in research by Bowen et al., (2017). In their research, the rate of injury occurrence in relation to a number of training load variables was monitored across a season in an elite youth football team. Results demonstrated that a high total distance, and overall training load can increase the risk of injury (Bowen et al., 2017). Additionally, a moderate-high volume of high-speed running distance resulted in greater overall and non-contact injury incidence (Bowen et al., 2017). Conversely, although chronic high training loads are related to heightened injury risk, when correctly prescribed, higher loads can also produce positive adaptations that build tolerance and resilience to fatigue and injury (Gabbett, 2016). However, lower volumes maybe be a risk factor too. Although lower accumulated workloads can demonstrate significantly reduced injury risk across training load variables (Bowen et al., 2017), it would be accepted that low workloads would not be recommended in professional practice. For example, football players can cover approximately 10,000m during a competitive match. As such, low weekly distances may result in the players being underprepared for the physical demands of the game, and ultimately may increase the risk of injury. This may be especially the case for high speed running volumes. There is potentially a fear of injury when performing high speed running in training, especially when leading into a game (see Project 1C). However, there could be an equally high risk by restricting players from performing HSR during training, where they become under-prepared to run at these speeds during match-play (Gabbett et. al., 2016). Results in our research suggest that there was no significant difference of training load variables between the two pre-season phases. However, pre-season 2 did have higher recorded values for each recorded training load variables (table 6). Therefore, it would be amiss for the authors not to comment on the possibility that the higher training loads (albeit no statistically significant) seen during pre-season 2, may have played a role in mitigating the rate, occurrence and severity of injury reported. Specifically it could be of interest to note that pre-season 2 contained more HSR distance (11228 m ± 4399 vs. 11571 m ± 4010). While overall TL is commonly reported with injury risk, research from professional football shows that an increased risk of injury occurs when HSR was higher than normal acute- and chronic-loads (Jaspers et al., 2018). Practitioners' commonly use HSR as a key load management metric because of its relationship to injury risk in a number of sports (Bowen et al., 2017; Duhig et al.,2016) while, management of HSR is considered the most valued strategy for preventing lower limb injuries within the 'Big 5' European Football Leagues (Fanchini 2019). In addition, Project 1C suggests that 73% of practitioners' believe that the increase in match play intensity and high-intensity actions may leave players at greater risk of injury, and 47% suggest the increase in our training day high-intensity actions may make the players more at risk of injury.

Despite a lack of agreement on the direct links between running loads and injury risk in professional football, the fact that there is a plethora of research examining the effects of training load on injury rate shows it's relative importance. This is why assessment of training load was included in this research. What our research shows is that training load was deemed not different between the 2 pre-seasons. Since no significant difference was observed, it appears training load in both pre-season phases had little impact on injuries, and thus gives further support to the notion that the inclusion of strength training could be the biggest contributing factor in reducing non-contact muscle and tendon injuries in this football team.

The physical demands of football match play are well known, where players typically cover distances of 10–14 km per match (Bangsbo, 2006). In contrast to match demands, the physical demands of training in elite professional players are not currently well documented and are limited to reports of a single-week exposure (Owen et al., 2014), average values over a 10-week period (Gaudino et al., 2013) and season-long analysis (Malone et al., 2015; Bowen et al., 2017). The physical demands of training place considerable demands on S&C, sport science and medical staff to monitor and manage training load to ensure optimal match-day performance and recovery (Morgans et al., 2014; Nédélec et al., 2014), whilst also preventing injury (Dellal et al., 2015; Dupont et al., 2010) and symptoms of over-training (Morgans et al., 2014).

Little direct comparisons to pre-season training volume are available in literature, and even if they were, these would likely differ greatly between each specific team environment. Comparison to previous research in elite football is often based on weekly exposures during the season (Andersen et al., 2016; Gaudino et al., 2013). As mentioned, acute and chronic high speed running exposure is considered a key variable for injury risk. In the current research, the average total high speed running exposure per player was 11228 and 11571m across the each pre-season phase (*total distance for squad divided by number of players, n= 20*). The pre-season phases included 24 and 25 sessions respectively. Therefore, the average HSR volume equates 467 and 462m per session. In comparison to previous, this would appear to be high. Research into the training load of Premier League teams reports average weekly HSR ranges from 164 – 476m (Gaudino et al., 2013; Andersen et al., 2016). The large disparity between the results could be a result of several factors. Primarily, our research was in pre-season, and the others are during the in-season period. Training loads are typically higher during pre-season than in-season due to the change in the training focus from conditioning and physical preparation in the pre-season, to more technical and tactical during the in-season (Jeong et al., 2011). Additionally, high HSR loads are typically seen within sessions incorporating large pitch sizes focusing on the extensive tactical and physical aspects of 11 vs. 11 match play (Kelly 2019). Again, these types of sessions that expose players to high physical demands are a key focus of training sessions during pre-season. Finally, the recording of training load in the current study included that of pre-season, non-competitive matches. While a number of the games played in both pre-seasons were against the same opposition (4 of the 6) which helps with the ecological validity of this study, other research does not include match exposure in their recording of training load (Andersen 2016; Gaudino 2013).

Strength training programme

Football is a high-intensity, intermittent team sport, which requires the development of multiple athletic qualities in order to optimise physical performance. For example, football players have been shown to jump up to 15 times during competition (Nedelac et al., 2014), perform 168 accelerations and decelerations (Taylor et al., 2017) and change direction between 1200-1400 times per game (Bangsbo, 1992). The key physical attribute that underpins these movements is strength (Suchomel et al., 2016). Furthermore, recent meta-analysis showed that strength was the most commonly programmed and effective physical component during training interventions aiming to reduce the risk of sports injuries (Brunner et al., 2019; Crossley et al., 2020). Among all training strategies traditionally used by strength and conditioning coaches, the inclusion of strength training has been shown to have the greatest preventative effect on reducing acute and overuse sports injuries; ahead of stretching and proprioception training (Lauersen et al., 2014; Brunner et al., 2019). Zouita et al., (2016) showed that strength training reduced the risk of injury in elite youth players during one season; reducing the injury rate from 2.32 to 0.7 per 1000 hours. It was also noted that approximately 50% of total injuries in the non-strength training group were classified as muscle strains; thus demonstrating the potential protective role of strength training on muscle injuries. However, unlike the current study, other related injury risk factors such as training load exposure were not mentioned or analysed.

In addition, a positive dose-response relationship between strength training and injury prevention has been reported whereby an increased exposure to strength training reduces the rate of injury (Lauersen et al., 2018). Consequently, it has been suggested that information and recommendation should be provided to S&C coaches on how to accurately design and prescribe strength training for non-contact injury prevention in football. Therefore the inclusion of strength training as the primary focus of the training programme is well supported and justified. Overall, the training programme implemented in this study was based on an understanding of research in addition to what has worked in this environment, with these players.

When designing a training programme many factors needs to be considered. These include, but not limited to session volume, frequency, intensity, and exercise selection. Manipulation of one or a number of these factors may determine the success or failure of a training programme. For resistance training volume and frequency, research has suggested that during the pre-season phase a minimum of 2 sessions per week, with 4 sets across 2 exercises should be conducted (Turner & Stewart 2014). In the current study, we conducted 8 resistance training sessions across the 6 week pre-season phase. A lower limb strength sessions occurred once per week during 4 of these weeks, and twice per week in 2 of these weeks. This was dictated by a number of factors such as the high session or weekly training load; international travel for pre-season tours; and proximity to games. Therefore, potentially increasing the frequency of these lower limb strength sessions may have resulted in a greater effect on injury rates (Laursen et al., 2018). However, as is the underlying narrative in this PhD, the nature of the 'real world' environment does dictate the implementation of any training intervention, and we couldn't, or didn't include an intervention solely for research purposes.

Nonetheless, given the short duration of the study, subject numbers and the low number of injuries reported, there may still have been non-significant effects on average injury severity with increased exposure.

Like session frequency session volume and intensity was periodised and progressed throughout the pre-season phase in respect of training volume, proximity to match-play and the adaptation of the player to match-play, and the adaptation of the player to the sessions, with the intention of allowing physical performance to peak for the beginning of the competitive season.

The EBS implemented during the pre-season 2018-2019 had a primary focus on improving lower limb strength (table 5). We focused on increasing general lower limb strength and subsequent overall injury rate, rather than focussing on a specific injury such as ACL or hamstring injuries like often reported (Askling et al., 2003; Walden et al., 2012). In addition, despite the pre-season phase being only 6 weeks in duration, and with only 8 S&C sessions incorporated in this phase, we still aimed to follow the principles of training (overload, variation and specificity), and work within the rep range and intensity reported for improving strength in athletic populations (Bompa et al., 2018), namely ~6 reps at >85% repetition maximum (RM). While benefits have been highlighted from training with different loading schemes such as 6-15 reps, and between 65 – 85% RM (Crossley et al., 2020); lower volume and greater intensity elicits "true strength' gains. Despite most research utilizing strength exercises successfully reducing injury rate, it has been suggested that many programmes do not follow these basic training principles (Crossley 2020). In addition, many programmes may not actually target strength, but more muscle endurance or movement quality (Bizzini & Dvorak, 2015). For example, Owen et al., (2013) incorporated a multiple component EBS during a full competitive season in a professional football team. For the first 10 sessions, which would equate to the pre-season phase, only a low volume of 2 x 4 – 6 repetitions was included on the 3 traditional strength exercises (Nordic Hamstring Exercise, Single Leg RDL, Split Squat), with the other 'strength' exercises programmed being 'glute activation' exercises (banded lateral walks, banded clams, bird dog). There was no mention of load or how load was selected, with the same exercises being programmed for the duration of the season. In fact, it was commented by the authors that "*despite the programme being performed during the entirety of the season, it is possible that the session or individual exercises themselves may not have been sufficient duration required to elicit large training adaptations*" (pp. 3283). In comparison, session 1 of our programme consisted of 8 traditional strength exercises, of which 5 exercises were comprised of 2 sets of 8 repetitions, at 70-80% 1RM, with the additional 2 exercises operating at high volume, based on individual repetitions from baseline testing (see table 4). This volume was selected due to it being the first session of the pre-season training phase. However, by session 4 during week 3, volume and intensity had both increased, whereby the players now performed 3-4 sets of 6 reps, at 80-85% 1RM.

The progressive overload of the strength training programme in the current study, rather than an strictly injury prevention programme may have an advantage in reducing injury risk in the short, and potentially long term. Furthermore, the periodisation of either short or long term programming promotes a focus on performance qualities, not just a reduction in injury rate. Additionally, exercises were varied to some degree across the training phase, with athlete individuality being considered. This type of programme design is recommended when resistance training is introduced, but the variation and progressive overload is needed to develop the athletes physical capabilities. In addition, the more advanced the athletes become in performing the exercise, the more variation may be necessary to avoid performance plateaus (Krustrup et al., 2009).

Eccentric exercises have been shown to be important in reducing injury risk in professional sport (McCall et al., 2015; Askling et al., 2003; Petersen et al., 2011) and are frequently used in professional football teams (McCall et al., 2015; Beere et al., 2020, Project One A). Interventions typically implement the Nordic hamstring exercise for enhancing the eccentric strength capabilities of the posterior chain, although the sliding leg curl (SLC) exercise has been proposed as an alternative due to the ability to vary the intensity and loading strategies (Taberner, O'keefe & Cohen, 2016). It has been advised to include both knee (i.e. Nordic hamstring exercises / Sliding leg curl) and hip (i.e. Romanian deadlift, RDL) dominant exercises to improve eccentric strength and increase fascicle length through the whole muscle and reduce the risk of hamstring strain injuries (Buckthorpe, 2019).

In addition to bi- or uni-lateral, compound exercises working within traditional strength adaption ranges (6 reps, 80% 1RM), implementing higher volume, muscle capacity exercises may be of benefit to increasing tissue robustness. For example, it has been shown that a deficit in SLHB score has been shown to increase the risk of hamstring strain injury during the subsequent in-season period (Freckleton et al., 2013). Each player would then complete their programmed number of sets, at a given intensity, but with an individual rep range (i.e. 50% of maximal SLHB score for player A could be 15 reps; whereas for player B it could be 25 reps). This ensured that intensity for a given session was controlled to the best of our ability across the playing squad.

Additional considerations

Results in this study show a positive trend for a reduction in injury rate and severity as a result of strength training. However, many types of injuries and injury rate still remains high and unchanged over an 18 year period (Ekstrand et al., 2021). While improvements are being made in a reduction of training and match incidence, Ekstrand et al., (2016) suggests an EBS aimed to reduce injury risk and occurrence should not only address the traditionally proposed modifiable factors such as strength deficits, poor flexibility, player load and match frequency, but also understand the importance of external factors such as coaching, medical staff and management consistency, player adherence and compliance to the programme (Ekstrand et al., 2016. While not strictly a direct methodological consideration, some of these factors were addressed in this study. For example, all coaching, medical and management staff were the same for both pre-season phases. This provides a consistency in approach and an understanding of each player. In addition, player adherence to the programme was high (76%) during the pre-season phase. Taken together, this is a positive design consideration in controlling some suggested related factors that may not always occur in evidence based research.

One of the main limiting factors for the effectiveness of EBS is the poor long-term compliance of players (O'Brien et al., 2016). Poor compliance may influence the rate of injuries (Bahr et al., 2015) and prevent understanding of the application and effectiveness of the EBS intervention (McCall et al., 2016). Based on the boundaries recently proposed (Ripley et al., 2021), compliance to this programme was very high (76%), which may help with the reduction in injury rates seen. However, while compliance can be defined as a strict flowing of the programme to the letter, this is not possible in the real world of professional sport. Many reasons can influence why all player may not follow the exact same programme all the time. These could be injury history, training and match volume or exposure, physical constraints such as poor ankle mobility, technical proficiency of an exercises, starting level of strength or training age.

The variation in results of EBS could also be due to the high level of individualisation from practitioners' when prescribing the programme. The injury prevention practices among elite adult football teams has been surveyed and examined (McCall et al., 2015a; McCall et al., 2015b; O'Brien & Finch, 2016). These studies have shown that despite practitioners' following a coherent approach, a number of the practices implemented are not well supported by research evidence (McCall et al.,2015a; McCall et al., 2015b; O'Brien & Finch, 2016). This is also shown to be the case in elite football academies (Read & Lloyd 2018). O'Brien et al., (2016) showed that delivery of the FIFA 11+ injury prevention programme in UK football academies varies depending on facility availability, exercise selection, exercise load and number of practitioners' available. In support of this, Beere & Jeffreys (2020) highlighted that poor facilities, and lack of staff are substantial barriers to successful S&C practice in elite football. Taken together, these studies represent football in the specific context of professional clubs where the training programmes, logistical demands and available facilities potentially differ to those utilised in recommended research Therefore, while compliance was high, and every effort was made for all players to complete the same fundamental exercises, there was the opportunity for individual programming in respect of content, volume and intensity. However, the aim of this research was not to suggest that "this exercise has to be done to reduce injury rate"; but more that general lower limb strength training can help reduce injury rate.

Limitations of the study

While this study shows a reduction in rate and severity of injury, this study is only reflective of one team only (albeit a team competing in the English Championship and Premier League) and hence may not be representative of the customary training demands of other domestic teams or those from other countries that may be influenced by different managerial and coaching philosophies. As such a number of a number of limitations are highlighted.

To provide any statistical significance, or even utilise any statistical analysis, a greater number of injuries would have been required, hence why only descriptive analysis was reported for injury incidence, injury rate and total severity. Due to the low number of total injuries (10 over 2 pre-seasons) and non-contact, muscle or tendon injuries (8 in total) in this study it may be difficult to infer a direct causation of the strength training programme on injury rates. However, a low injury rate should be seen as a positive for the practitioner, and it would this is more important than high rates for the sake of research.

In addition, as statistical power relies on the number of injuries, injury prevention studies require a large number of participants as the injuries are often infrequent. The 20 players used in both pre-season phases may not be considered a 'large number', but this is a result of the nature of the first team, professional football environment, and could be considered large when compared to many studies in the same situation. However, ultimately, the low injury rate and subject numbers provides further support for the ecological validity of this study.

Results from this study are from a 6 week pre-season phase. Although this study provides important information, it may be of interest to view how a training intervention continues to effect injury rates during early and later phases of a season. Although injury rates across two seasons can be compared (Owen et al., 2013) controlling training load, match exposure, travel and scheduling across two seasons to allow the same level of comparison as in this study, or to highlight the correlation between strength training and injury risk is too difficult to control. For example, although the two pre-season phases in this study were deemed similar, once the season started they would have produced completely different training and match exposures, mainly due to the step up from Championship to Premier League football where the number of league fixtures decrease from 46 to 38, and the physical demands are likely to increase. Despite some of these potential challenges, understanding any relationship across a full season will provide practitioners' and coaches with a greater belief in the benefits of incorporating S&C practices in professional footballers.

Finally, suggestions could be made to include other teams for analysis during a pre-season phases, as the results of this study are only reflective of one team, and hence may not be representative of other teams situations. Extrapolation of data across multiple teams with future studies will increase the sample size, injury incidence and a greater statistical analysis of results.

Future research direction

While the information obtained from this study are valuable, it also opens up questions for future research. While showing that strength training can help reduce injury rate is of significance to the practitioner, it may be of further interest to include performance test outcomes such as CMJ, speed, or strength scores to see if the inclusion of strength training not only reduces the risk or injury but also increases the athletic qualities of footballers during this period. Furthermore, it would be beneficial to see the effects of strength training on training or match related performance outcomes such as amount of sprint or high intensity distance covered. It is probable that not all load is equal, and that some stimuli (e.g. exposure to high-speed or sprint running) are more important than others from an injury perspective. Therefore, understanding how training load variables such as amount of HSR distance or sprint frequency may be enhanced by increases in strength training volume or athlete strength would also be of interest for the practitioner. For example, does an increased frequency of S&C exposure or stronger players, cover greater HSR distances or perform a greater number of sprints during match play. From personal experience, many players like to see how their S&C work translates to tangible improvements to their ability to perform during matches.

Finally, to create a greater level of buy-in from management or the club as a whole, practitioners' could also report the findings in relation to the team performance (points or change in league position) or financial cost of an injury to the club.

Practical Application

The practical significance of the findings that injury rate, severity and incidence appear to be reduced with the inclusion of strength training during the pre-season phase should be important to practitioners' working with professional football players. Prevention of preseason injury is important to ensure availability of players for the commencement of the season and to decrease the risk of injury later in the season.

The training programme highlighted in this study focusses on strength development for physical performance improvements as well as injury reduction. The practicality of the programme is key for use in team environments as it "it kills two birds with one stone", reducing the need to provide separate injury prevention and performance sessions. As such, it appears that practitioners' can include resistance training exercises utilising traditional strength training rep ranges, and higher rep muscle endurance, isometric and eccentric exercises. It appears that prevention of injuries is a transparent part of a thorough, well developed overall training plan, and that 'injury prevention' and 'performance' should not be exclusive of each other. Given this knowledge, it could be suggested that there is no need to focus on a specific injury reduction strategy, i.e. ACL or hamstring, if the overall training programme covers a wide spectrum of exercises (unless the athlete has a history of a specific injury). As a result, we recommend the implementation of a strength training programme that includes traditional S&C exercises targeted at improving physical performance and reducing injury risk.

It should be noted that compliance of players to the strength training programme was high (76%). This maybe just as important to the reduction in injury rates as the content of the sessions itself. This may be useful to the practitioner when deciding on appropriate training strategies that engage players and staff to promote high levels of compliance to the programme.

The information provided in this study can help coaches become more knowledgeable about including strength training into a pre-season phase that may help reduce soft tissue injury rate. Consequently, improving S&C coaches' understanding of why and how sports injuries are prevented may promote uptake of targeted strategies and help S&C coaches fulfil this responsibility with the profession.

Finally, we must also continue to embrace all strategies that are useful to prevent injuries. Even at the elite level, implementation of preventive exercises and player compliance to these exercises can be further improved, even though the standard is already high in many clubs (Bahr et al., 2015).

Conclusion

In conclusion, the results of the present investigation demonstrate that the inclusion of strength training during a pre-season phase can help reduce non-contact muscle injuries in professional footballers, with the greatest impact on mild – moderate time loss injuries.

Despite most injury prevention studies utilizing strength exercises to successfully promote the reduction in injury incidence, it appears that many programmes do not follow basic training principles such as progression in exercise selection, intensity and training volume (Crossley et al., 2020). This may be due to a lack of time available, understanding of what true strength is, or it mis-representation of the definition of strength training. Thus, it appears that there is still scope to conduct training interventions using traditional resistance training methods**,** with heavier loads that are targeting specific increases in strength (i.e. >85% 1RM) and some form of periodisation, overload and progression in football players, as evident in this study.

Our analyses supports the notion that frequency and intensity strength training and injury prevention are closely related. We believe the evidence provided in this article is sufficient to warrant a paradigm shift from the current dominance of multicomponent prevention programmes towards strength training programmes as the primary intervention to prevent sports injuries. It is my opinion that an overemphasis on either ‘injury prevention’ or ‘performance training’ may lead to injuries. In my opinion, prevention of injuries is a transparent part of a thorough, well developed overall training plan, and that ‘injury prevention’ and ‘performance’ should not be exclusive of each other.

PROJECT 3

CHANGES IN ISOMETRIC PEAK FORCE PRODUCTION AND RATE OF FORCE DEVELOPMENT IN PROFESSIONAL FOOTBALL PLAYERS OVER A COMPETITIVE SEASON: A DESCRIPTIVE ANALYSIS OF TRENDS

Abstract

Introduction: S&C practitioners' within football must understand how key neuromuscular characteristics such as strength and rate of force development (RFD) are likely to change within a full season and which factors are likely to affect the development or maintenance of such qualities. Very little information exists detailing season changes in physical performance, with no focus on these changes at different phases of the season.

Materials and methods: 18 senior, male professional football players (26.43 ± 3.1 years; 184.33 ± 4.6 cm; 84.34 ± 7.1 kg) were involved in this study over the course of a football season. Isometric posterior chain force and RFD were assessed at 12 separate time points. Group, sub-group and individual analysis of changes in peak and mean force, and RFD were reported.

Results: The analysis of trends across the full season (T1-T12) showed small to moderate magnitude increases in mean and peak force, RFD_{100} and RFD_{200} for the group. Sub-group analysis showed that the LB-force group showed a trend towards a greater positive adaptation in mean and peak force, as well as RFD_{100} and RFD $_{200}$. However, the high-force group showed less variability across the season, with less overall improvement, but also less decline in force characteristics during the congested period.

Conclusion: Isometric force and RFD can be increased across a football season. Baseline strength appears to affect the magnitude of individual response seen across the season and within specific phases. Changes in force production across a season are likely to be influenced by a number of factors such as match play, the resultant accumulation of fatigue, and response to a resistance training stimulus.

Key words : rate of force development; football; force; isometric; individual response

INTRODUCTION

Elite football players compete over long competitive seasons, often with multiple games per week (Meckel et al., 2018; Dellal et al., 2013). Given that decisive games with larger consequences, such as play-offs, knockout stages of competitions or cup finals, often take place towards the latter part of the season it is vital that key physical qualities are maintained, performance is high, and injuries are minimised throughout the entirety of a competitive season. Those involved in physical preparation must therefore strike a difficult balance between training to improve performance capacities and providing adequate rest and recovery to ensure optimal performance on a weekly or bi-weekly basis. It is unknown whether the involvement in competitive matches alone provides an adequate stimulus for the adaptation of physical characteristics such as speed, strength and power to occur; or if additional stimuli in the form of lower limb strength training will help optimise performance adaptation. Therefore, in order to understand how best to prepare their athletes, S&C practitioners' within football must understand how key neuromuscular characteristics such as strength and rate of force development (RFD) are likely to change within a full season and which factors are likely to affect the development or maintenance of such qualities.

The introduction section of this project will discuss:

- The outline of a football season and how it is divided into numerous specific phases.
- Current evidence into the adaptive changes in physical performance across and within these specific phases of a competitive season; with a focus on changes in aspects of dynamic and isometric neuromuscular (strength, power and RFD) performance
- Assessments frequently used within sport and football to monitor alterations in neuromuscular performance The isometric posterior chain test is an assessment of

neuromuscular function that has been principally reported in relation to examine match-related acute and residual fatigue responses, rather than the potential positive adaptations in response to training. This may be of use to S&C practitioners' seeking to evaluate the effectiveness of programming. Reports of neuromuscular function across a season in football have used the counter movement jump (CMJ), isokinetic dynamometry (for knee extensors), repetition maximum (RM) of a squat variation, or isometric mid-thigh pull (IMTP). At present, there are no studies that have reported isometric-posterior chain (IPC) force and RFD across a season.

- Finally, how analysis of the group, sub-groups and individual athletes provide different levels of athlete response to the concurrent nature of a football season. The analysis of the sub-groups aims to understand if the physical qualities of an athlete act as a potential mediator of response to concurrent competition and strength training. The analysis of individual response is to examine the individual variability across the group, and / or within the sub-groups.

The outline of a football season

A football season is typically divided up using a phasic model of periodisation based around an off-season, a pre- season and a competitive season (Silva et al., 2015). The off-season has been defined as a period of the year combining active rest and individual preparation prior to the start of scheduled technical and tactical training (Gamble, 2006). The pre-season involves heightened training volumes; consisting of concurrent technical and tactical practice and features a high intensity regime of physical training targeting multiple, football related components of fitness (Faude et al., 2013; Calleja-Gonzalez et al., 2020). There will often be progressively more match like practices and this period may feature some full matches which are outside the clubs competitive league or cup fixtures. The pre-season phase is considered a critical training period for professional football athletes. The aim of this phase is to develop key physical characteristics (e.g. aerobic conditioning, strength, power, speed) whilst competitive match play requirements remain low. The competitive season can be considered the period of the year where the team are actively involved in an increased fixture density, whereby the focus often shifts from conditioning to match preparation and increased fixture density (Carling et al., 2012). It is well known that football schedules are often chaotic in nature and constantly changing. This is due to several factor which may include television rights and progression through knockout tournaments. This can result in many teams playing multiple times per week (Dellal et al., 2013). At the elite level, a football season can have up to 60 games over a 9-10 month period. This elongated competitive phase will influence the treatment effects (i.e. resistance training dosage) of S&C training protocols and subsequently alter athlete strength development, retention and decay potential. In addition, the in-season phase can be further broken down into more specific sub-phases of early; congested; and mid-end season. Fixture congestion can be defined as a minimum of two successive bouts of match-play separated by <96 hours is a frequent and contemporary issue in professional football (Jullian et al., 2020). Congested fixture periods can be associated with reductions in performance and increased rates of muscle injury (Carling et al., 2012; Dupont et al., 2010).

Changes in physical performance characteristics

The basic demands of many sports require athletes to rapidly exert high forces to accelerate, decelerate or change direction (Suchomel et al., 2016; Cormie et al., 2011; Fraude et al., 2012; McBride et al., 2009; Wisløff et al., 2004**).** Resistance training, focussed primarily on the development of strength, is critical for improving athletic development and underpins both individual and team sport performance (Suchomel et al., 2016; Suchomel et al., 2018). In elite football, strength development is frequently prioritised by practitioners' aiming to improve performance and prevent injuries (Beere & Jeffreys, 2020; Project 1a; Weldon et al., 2020). This practice is supported by evidence through numerous studies demonstrating moderate-to-large correlations between maximal strength and dynamic performance (Suchomel et al., 2016).

The existing literature in the field of S&C contains an increasing volume of evidence regarding the application of S&C programming in football (Owen, et al., 2013; Turner & Stewart, 2014; Comfort et al., 2014; Zouita et al.,2016; Loturo et al., 2018). However, it is important that the outcomes of these studies are viewed within the context of the professional male football environment. Research of S&C practices in football are often limited to smaller time frames (e.g. 4-12 week blocks (Bogdanis et al., 2009; Rønnestad et al., 2011), Academy aged players (Bishop et al., 2020; Emmonds et al., 2018; Zouita et al., 2016) or focussed on managing injury rates (Owen et al., 2013; Zouita et al., 2016). Whilst these studies have importance, the results may not reflect the adaptation potential of well-trained professional football players, where the concurrent training environment, the principle of diminished return, and the time-limited nature of a competitive season are all factors which make athletic development harder to achieve (Argus et al., 2009; Cormie et al., 2010b; Crewther et al., 2013). In addition, neuromuscular function response may be influenced by the training status / history of an athlete, their individual response to training and competition loads, and the assessment modality (Johnston et al., 2015; Rowel et al., 2017; Maffiuletti et al., 2016). For example, it has been shown that improvements in muscular strength and power are achieved with relative ease in short term studies in untrained individuals (Cormie et al., 2007a, Comfort et al., 2020). However, while the findings highlighted by Comfort et al., (2020) are of interest, the study of 2 x 4 week meso-cycles means that these findings cannot be extrapolated to a full, 38 week professional football season, whereby fatigue and performance interact when these cycles are periodised sequentially. At present, few longitudinal studies have adopted within-athlete experimental designs which may better inform neuromuscular function based decision making in professional sport. Therefore, applying the findings from shorter duration studies to a professional sport environment can be challenging. It has been suggested that research led best-practice is not more frequently applied in the practical setting of professional male football due to some of these discrepancies (Beere & Jeffreys, 2020; project 1b). For effective and efficient S&C practices to be developed in this environment, a greater knowledge of the force production characteristics across different phases of a professional season (e.g. pre-season and in-season) is required.

Changes in physical performance characteristics : Pre-season

The pre-season phase has been demonstrated to initiate improvements in measures of strength and body composition (Suarez-Arrones et al., 2019; Helgerud et al., 2011); strength and endurance capabilities (Helgerud et al., 2011) and vertical jump performance (Fessi et al., 2016; Wong et al., 2010) in professional football players. Specifically, Helegrud et al., (2011) showed that half-squat 1RM increased by 51.7% and jump height by 3cm in elite football players when completing half-squat strength training twice a week for 8 week pre-season period. In addition, several studies have focused on the changes in maximal strength occurring during the pre-season phase in other team sports (Argus et al., 2010; Gannon et al., 2016), whereby significant improvements in lower- and upper- body strength have been seen. Studies incorporating the CMJ assessment as the marker of physical performance change show that vertical jump performance (as measured in change in jump height) tends to improve in professional football players when weight and plyometric training is performed frequently during the pre-season phase (Fessi et al., 2016; Wong et al., 2010). However, what they don't tell us about adaptations are how these pre-season improvements in strength and jump performance may carry over into the in-season period and affect physical performance outcomes for longer periods of time. In fact, while Helegrud et al., (2011) showed improvements in pre-season period, there was no further investigation into the changes during the in-season. In addition, Fessi et al., (2016) and Wong et al., (2010) demonstrate improvements in vertical jump performance during the pre-season, but show no further change during the 2 further assessments in the competitive season. While improvements in strength or jump performance are useful to the practitioner, how these changes continue through the following 8-9 months should be of greater interest.

Evidence suggest that the pre-season phase is a window of opportunity to promote improvements in physical performance in strength and jump height output. Given the importance of the pre-season phase in football, and the potential that the adaptations experienced during the pre-season phases (combination of strength training, match and training) may influence adaptations in the in-season (Rønnestad et al., 2011), it is could be questioned why more research has not been conducted to highlight how these changes can be carried over into the in-season phase. This investigation aims to address these voids in current research by frequently analysing changes in force output not only through the pre-season phase, but also during specific phases of the entire football season. This will help create an understanding of how force production changes in relation to periods of fixture density and lower limb S&C frequency.

Changes in physical performance characteristics : In-season

During the in-season phase, where congested fixture schedules often exist, increasing or even maintaining levels of strength potentially achieved during the pre-season can become a complex task. This can be a result of greater levels of fatigue derived from match play (Anderssen et al., 2008; Ascensao et al., 2008), reduced availability of training volume (Gamble et al., 2006), the interference effect of concurrent training (Blagrove et al., 2013), and the need to continually peak athletes for competition (Turner & Stewart, 2014).

There is currently limited research examining changes in strength performance over a competitive season in elite professional football players (Eniseler et al., 2012). There is only one study that tracks changes in strength across a season in professional male football (Eniseler et al., 2012), where an increase in knee extensor and flexor isokinetic strength was demonstrated across a 24-week season in Turkish football players. Although not conducted over a full season, Rønnestad et al., (2011) reported an ability to maintain 1RM half squat strength during the first 12 weeks of an in-season phase as a result of strength training once per week in elite footballers. Relative strength, as measured with the isometric mid-thigh pull (Emmonds et al., 2018) and adductor and knee flexor strength (Jones et al., 2021) have shown likely increases across a full season in Academy aged football players.

While the reporting of changes in strength across a season is limited, it appears bilateral jump tests are the primary method to track longitudinal changes in performance in senior male football (Papadkis et al., 2015; Haugen, 2018) and elite male academy football (Bishop et al., 2020). This may be due to the simple and time efficient method that can be commonly used in professional football (Beere et al., 2020; Paper 1a). In professional Greek footballers, Papadkis et al., (2015) showed a positive overall trend for CMJ height, but demonstrated a drop off in CMJ height between the mid and end of season. Haugen (2018) analysed the season variation in jump height performance in professional Norwegian footballers, and reported significant increases from pre- to post-season. The studies presented here look at in-season periods ranging from 12 to 42 weeks. Given the short duration of some studies, and the fact the subjects were from teams following a different annual league structure to the that of the majority of British football leagues it is unclear how useful these results are to the strength and conditioning practitioner in the UK. It has been shown that greater competition exposure over a longer competitive season is likely to lead to higher levels of cumulative fatigue and increased risk of injury, with a subsequent decrease in performance (Ekstrand et al., 2011).In addition, whilst these studies show a general trend of strength or jump height improvements over a season, the frequency in which these outcomes were measured represents a limitation in explaining likely changes in performance over a long competitive season. For example, in the Eniseler et al., (2012) study, performance was only measured twice; pre-and post-season / intervention. Likewise, Haugen (2018), Bishop (2020) and Emmonds et al., (2018) only measured performance at 3 time points, and Papadkis et al., (2015) only measured performance at 4 periods within the season. One-time only or limited assessment has been shown to have limited value for preventing injuries (Bahr et al., 2016), whereas multiple repeated measures of performance should be undertaken to evaluate the response to a training programme (Mann, 2011). Subsequently, without knowing the likely magnitude and direction of change over more frequent specific phases of a season it is difficult for practitioners’ to prepare optimal strategies to maintain or develop physiological characteristics important to success in professional football. In addition, these studies with limited frequency of repeated measures of performance would not have picked up fluctuations associated with fixture or training density, and changes in in strength and conditioning programming content, and thus may provide little meaningful, practical implications for practitioners'.

The implementation and the effects of delivering a strength training programme alongside a competitive schedule across a whole season has not been examined in footballers. Often studies highlighting changes in performance neglect to include comments on the concurrent influence of match play and strength training frequency and density, implying that any changes are a result of the intervention alone. Concurrent training, described as the simultaneous performance of strength training alongside aerobic conditioning, is synonymous within football performance (Enright et al., 2015). Understanding the value and effect of concurrent training is important when applying research guidelines and interpreting the findings. It should be acknowledged that match play and training fatigue may have a great impact on changes in force, rate of force development (RFD) and jump height reported in footballers. Due to the potential interference effect of concurrent training, the effects of acute and chronic fatigue and the lack of time available for additional S&C, it is unknown if strength can be improved, or even maintained across a fully competitive professional football season.

Due to the increased demands of technical training and competition, the outcome of in-season S&C programmes is often a maintenance of strength and power, after improvements are made during the pre-season period (Rønnestad et al., 2011; Eniseler et al., 2012; Gannon et al., 2016; Turner & Stewart., 2014). In-season strength maintenance has been exhibited over a 12-week period, whereby Rønnestad et al., (2011) demonstrated that strength training once per week over the first 12 weeks of the season permitted the maintenance of strength gained in the pre-season when compared to one session every two weeks which resulted in an average loss of 10% 1RM half squat. This has led some reports to state that the aim of in-season training should be to maintain, rather than increase strength and / or power levels (Turner, 2011; Turner & Stewart 2014). For sports where there are regularly ≥ 2 games per week, and a large technical-tactical focussed approach, there would be a potentially detrimental long-term effect if athletes were not be able to maintain strength throughout a full season. Focussing on ‘maintenance’ is arguably a poor training goal during long seasons, especially given the fact that small but progressive increases in performance can be achieved in professional athletes (Baker, 2013). In addition, the ‘maintenance’ approach may disadvantage the developmental athlete (those who need greater increases in athletic capabilities e.g. young players transitioned in senior football) who, therefore, may never achieve their full potential as a result. Despite the lack of data that currently exists tracking the extent and magnitude of adaptation during a full competitive season in professional senior football, beneficial increases in several parameters of strength performance have been identified in response to strength training during a Rugby Union (Appleby et al., 2012; Gannon et al., 2016), Rugby League (Baker & Newton 2006) and Aussie Rules (AFL) season (Norris et al., 2021). However, it must be noted that there are different physical requirements for rugby and AFL, and in addition these sports often play a 1 game per week schedule, unlike football which often requires athletes to perform multiple times per week (Baker, 1998; Dellal et al., 2013) and therefore these results may not be applicable to elite male football.

Rate of force development

While maximum strength may serve as the foundation for improving various athletic performance capabilities, literature has indicated that the ability to rapidly produce high levels of force is one of the most important characteristics of athletic performance (Harris, Cronin, and Keogh, 2007). Given the short duration and explosive nature of many important muscular actions within football, such as ground contact time in sprinting (Weyand et al., 2010), jumping (Cormie et al., 2010) and change of direction ability (Spiteri et al., 2013), it is likely that rate of force development (RFD) has a high level of functional significance (Harris, Cronin, and Keogh, 2007). RFD can be defined as the rate at which muscular force rises at the onset of muscular contraction (Aargard et al., 2002). Strong relationships have previously been reported between isometric RFD, jumping and Olympic lifting performance (Haff et al., 1997). It appears that dynamic and isometric RFD is largely determined by factors such as motor unit synchronisation and firing frequency (Cormie, McGuigan and Newton, 2011a). Given the likely neural nature of this quality it is possible RFD is sensitive to levels of fatigue likely to be observed over a football season.

Research has shown that RFD can be increased with strength training in athletes (Comfort et al., 2020). However, despite the probable significance of improvements in RFD to athletic performance, no study has reported changes in this parameter over the course of a professional football season. Comfort et al., (2020) demonstrated that high load strength training results in improvements in rapid multi-joint force production in youth football players. These findings are similar to those that have been demonstrated an increased RFD during single joint, isokinetic dynamometer (Aagaard et al., 2001), and multi-joint squat strength interventions (Bazyler et al., 2014). However, as previously mentioned, the study of 2 x 4 week meso-cycles (Comfort et al., 2020) means that these findings cannot be extrapolated to a full, 38 week professional football season. In addition, the results were found in youth athletes, where strength increases have previously been seen to improve RFD in untrained individuals (Minettiet al., 2017), but that similar protocols have not elected gains in more experienced athletes.

There are certain methodological factors which need to be considered when assessing RFD which may be a reason for the lack of reports into RFD in professional sport (Maffiuletti et al., 2016). The evaluation of RFD is quite challenging from a methodological point of view: much more than the simple assessment of pure maximal voluntary contraction (MVC) strength. Primarily, the large variability in rapid muscle activation capacity at the onset of the contraction suggests RFD assessment should be conducted with particular care. It is notable that RFD measures can be less reliable than MVC force (Tillin et al., 2010) and substantially so during the early phase of contraction (Buckthorpe et al., 2012). Therefore, there is a need for a strict methodological approach to maximise reliability and to collect worthwhile data, which may not always be easily adhered to in professional sport. Active tension in the muscle prior to the onset of an explosive contraction (pre-tension) alters the shape of the rising force-time curve, increasing the initial torque-time integral (de Ruiter et al., 2006) and decreasing peak RFD (Van Cutsem and Duchateau 2005). Therefore, pre-contraction conditions should be standardised across contractions, participants and sessions to ensure reliable measures of RFD. In the practical setting, standardising the pre-contraction conditions can be done by providing a visual of the force-time graph, to provide feedback to participants and rejecting attempts where the baseline force is not sufficiently stable (Tillen et al., 2010, Blazevich et al., 2009).

In addition, RFD measurements are sensitive to the instructions given. It has been suggested that athletes should be encouraged to achieve high peak force even if the emphasis is on contracting as fast as possible to accurately measure RFD. It can therefore be suggested to instruct athletes to contract as “fast and hard” as possible with the emphasis on the fast / explosive / rising phase of contraction (Maffiuletti et al., 2016), with feedback given to the athlete after each trial (Tillin et al., 2010).

Despite the difficulties in assessing RFD, isolated single-joint tasks - such as the IPC test - typically provide an experimentally controlled situation in which to assess the underlying physiological determinants of RFD.

Changes in physical performance characteristics : Rate of force development

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Based on current literature it is unclear whether improvements in RFD can be made over the course of the pre-season or in-season period in professional football players. Since no studies have examined changes in RFD compared to match or training load over a season in professional football players it is unclear if any change in match density or change in strength training density has any impact on RFD output. While no study exists in football, recent research has assessed rate force characteristics across an elite Australian Football (AFL) season (Norris et al., 2021) using the IMTP assessment. Results showed that RFD_{100} and RFD_{200} demonstrated a significant negative seasonal trend. Despite the differences in sport, and isometric assessment, it could therefore be inferred that seasonal reductions in RFD would occur in professional footballers as well, mainly due to match-related fatigue.

Without knowledge of the likely effects changes in match-play and strength training have on neuromuscular performance in professional football it is difficult for practitioners' to prepare optimal in-season strategies to maintain or develop these important qualities. Therefore, examining the trends in RFD across a season, analysing the changes in relation to concurrent match play and strength training, will provide practitioners' with new information that may help physically prepare elite footballers for the demands of the season.

Monitoring of performance: Assessment of force production

While designing training programmes appears to be the first step of training management, monitoring the impact of the sessions on players appears to be a secondary step towards being successful in the training process (Djaoui et al., 2017).

The perceived importance of monitoring assessments in professional football has previously been highlighted (Drust 2019, Beere & Jeffreys, 2020; McCall et al., 2015; Akenhead & Nassis, 2016), whereby a multitude of monitoring strategies are often in place. Drust, (2019) reported that the number of touch points between staff and Premier League football players ranged from 3 – 7 per day. In terms of training load monitoring alone, Akenhead and Nassis, (2016) found that practitioners' recorded 7 ±2 variables when monitoring for training load. In a survey of practitioners' in elite football, Beere & Jeffreys (2020) reported that on average, 9.8 performance variables were measured during the pre-season, and 9.7 performance variables were measured during the in-season.
The main reasons why practitioners' assess and monitor performance variables are to improve performance, to prevent injury (Akenhead & Nassis, 2016; Beere & Jeffreys, 2020) and manage training load (Akenhead & Nassis, 2016). There is particular interest in neuromuscular performance characteristics that can be screened for, and potentially addressed, with effective training interventions. These could be inadequate hamstring strength (Timmins et al., 2015) and/or inter-limb strength imbalances (Bourne et al., 2015; Fousekis et al., 2011). To truly understand and evaluate the adaptation response to a training programme, multiple repeated measures of performance should be undertaken across a season (Mann, 2011). This may help the practitioner understand the trends associated with

training, match play and strength loading that may appear during different phases of the season.

Most research repeats measures of performance only twice; pre- and post- intervention; or a small number of times across the intervention period (Eniseler et al., 2012; Haugen et al., 2018; Bishop 2020; Emmonds et al., 2018; and Papadkis et al., 2015). Regular assessment of physical performance may provide more useful information to the practitioner to help inform decisions on training load, match participation, recovery strategies, alterations in strength training provision or warrant further examination of the athlete (Borresen et al., 2009; Kiely 2012). In addition, the response to exercise may differ within the same person on different occasions (Mann, 2011). For a given number of subjects, relying on means from repeated assessments before, during and after the training intervention (instead of a single measurement) reduces the associated within-subject random variation. In other words, means of several observed values are a better estimate of the true value for an individual than a single observation.

Currently, assessment of neuromuscular function in the world of professional sport has largely used a range of dynamic contraction modalities such as sprint and jumping protocols (Halson, 2014; Taylor et al., 2020; Twist & Highton, 2013; Beere & Jeffreys, 2021; project 1b). In particular, jumping protocols are most common (Beere & Jeffreys, 2021; project 1b), given their ease of implementation, where time constraints and squad sizes are key factors for consideration in elite sporting environments. The dynamic requirement of jumping protocols however, may preclude athletes who are sore or injured from being able to complete a required trial. A potential solution to the problem may be testing neuromuscular function with an isometric contraction. Traditionally these assessments were commonly performed in laboratory settings using expensive and importable equipment such as isokinetic dynamometers. More recently however, the IMTP and isometric posterior chain test (IPC) have become increasing used as a strength profiling tool in elite sport settings (James et al., 2017; Comfort et al., 2015; McCall et al., 2015; Tabener et al., 2018; Beere & Jeffreys, 2021).

Aside from changes in performance, research in football is frequently focussed on one specific area, such as hamstring / posterior chain strengthening or reductions in injury risk (Bhar et al., 2015). Nordic eccentric strength and posterior chain isometric strength testing are commonly employed measures of posterior chain strength in professional football (Beere & Jeffreys 2021). There is a wealth of knowledge suggesting that eccentric strength, or the lack of, is a strong predictor of hamstring strain injuries (Bhar et al., 2015), and eccentric exercises are regarded as highly effective in preventing injuries by football practitioners' (McCall et al., 2015a; McCall et al., 2015b). Practical based research of the isometric posterior chain (IPC) strength test has become more common, as it can be implemented as part of weekly monitoring aimed at quantifying residual fatigue in the days following competition or return to play following injury (Schache et al., 2011; McCall et al., 2015; Wollin et al., 2018; Taberner & Cohen, 2018; McCall et al., 2014; Constantine et al., 2019; Nedelec et al., 2014).

Despite research supporting the use of Nordic hamstring exercise, uptake and adherence is often poor in elite football (Bahr et al., 2015), with negative perceptions from players and practitioners' towards the exercise, with worries of increased risk of delayed onset of muscle soreness (DOMS) often cited as the reasons why adherence is poor (Beere & Jeffreys 2020; Petersen et al., 2011). Therefore, despite the body of research in support of eccentric hamstring testing and monitoring, isometric strength testing may be more applicable to the day-to-day environment of professional football. Isometric testing may provide an alternative method for monitoring and tracking neuromuscular strength changes in football players across the season due to the relative ease of assessment, reproducibility, non-fatiguing nature and minimal associate injury risk, that may allow practitioners' to use it consistently throughout the season, even during periods of heavy fixture congestion. Furthermore, explosive force-time measures (rate of force development) collected from isometric testing may have a potential advantage of giving insight into the mechanisms of neuromuscular fatigue or function. This is important as RFD is an indicator of explosive strength and a neuromuscular quality that may better predict athletic performance (Harris, Cronin, and Keogh, 2007) than peak force in activities such as sprinting (Weyand et al., 2010), jumping (Cormie et al., 2010) and change of direction ability (Spiteri et al., 2013).

Ultimately, whatever monitoring system is utilized, regular assessment to track changes across a season is needed to fully understand trends that may occur at specific phases of the season. Therefore, this current study will monitor force changes at 12 points across the season, allowing for an analysis of trends that occur at the key phases of a competitive football season.

Group, sub-group and individual responses

A key utility of monitoring neuromuscular function in elite sport settings is gaining insights into the individual response to a given training and / or competition stimulus. Resultant information could help the management of acute recovery strategies or long-term athletic development plans. Complexities in reporting individual responses may be attributed to the high degree of between-match load variations incurred during matches (Kempton et al., 2015) and an assumption that load is tolerated equally by athletes of differing training status or physical phenotype, and by the same athlete consistently. Therefore, in addition to factors such as load and phase of the season, moderators on neuromuscular function response should be examined. It has been shown that baseline physical qualities may also influence the capacity for adaption over a season (Baker & Newton, 2006; Norris et al., 2021).

Longitudinal experimental designs are necessary to determine the interactions between physical qualities such as baseline strength, and load upon neuromuscular function responses. In non-athletic individuals, research has shown that identical strength training programmes may cause diverse individual responses (Ahtiainen et al.,2016; Peltonen et al., 2018, Hubal et al., 2005). Researchers have reported differential adaptations between weak and strong athletes (Cormie et al., 2010) whereby improvements in strength are easier to come by in those weaker athletes.

As well as the level of response varying between differing levels of strength, it has been proposed that different training stimuli could evoke similar chronic training responses between individuals (Cormie et al., 2010). In other words, an athletes' individual physical qualities may benefit from a specific stimulus at a given time point (Cormie et al.,2010). Cormie et al., (2010) show that once a level of strength has been achieved, stronger athletes need a power stimulus to improve production capabilities, whereas weaker athletes can improve power output from strength training alone. As such, we will analyse trends in seasonal force output in 2 sub-groups; those who are classified as low or high force producers based on baseline testing (T1). As suggested, the response to exercise training may not only differ between athletes (Bouchard, 2001; Mann et al., 2014), but also within the same person on different occasions (Mann, 2011). Within elite team sport, players might experience training loads that are either excessive or suboptimal, especially during in-season phases when increased or decreased involvement in training and matches occurs (Thorpe et al., 2016). Understanding individualized training responses therefore requires frequent monitoring and reporting of changes in physical qualities (Buchheit, 2014).

Although many studies have reported that various resistance training modalities can promote positive responses in professional athletes (Gannon et al., 2016; Rønnestad et al., 2012, Helegrud et al. 2011), such studies typically only consider the group response to an intervention to determine its overall effectiveness (Mann, 2011). Whilst practitioners' have long understood there is variation in how their athletes respond to a given training stimulus, researchers often only report such variation through the reporting of standard deviations or standard error. As such, there is limited data highlighting the individual response vs. the group response to training in professional athletes. Although reporting the mean and standard deviation within the group is a useful way to describe the variation in response, only viewing this may conceal a wide range of individual responses, such as high-, low- and negative responders (Mann et al., 2014). Subsequently this may result in findings that may be overly simplistic and potentially misleading. In addition, for studies with small sample sizes, the data may not adequately represent a normal distribution and the assumptions based on standard deviation are less likely to be accurate (Mann 2011). Consequently, to further explore the responses at an individual level, magnitude of change as represented by percentage change will be reported for each athlete.

Therefore, the trends of group, sub-group (based on relative strength) and individual responses during a competitive football season will be reported in this investigation. The current study aims to determine trends in: group response; sub-groups of low or high force producers; and individual high-, low-, or negative responders to concurrent match, training and strength training via the assessment of isometric posterior chain force output.

Justification for research

The available literature shows that force, and the ability to rapidly produce force are related to success in football (Baker, 2002, Smart et al., 2014). At present however limited information exists regarding the longitudinal changes in strength and RFD that occur during specific phases of a season in elite male footballers. Without information suggesting the direction and magnitude of likely changes in strength and RFD it is difficult for coaches to best plan their physical development strategy. Moreover, trends in RFD over the course of a whole season in professional football have never previously been reported. The limited findings of studies within football make clear conclusions regarding strength change during the competitive season difficult to draw. Furthermore, with only one study investigating strength change over a whole season in football (Eniseler et al., 2012), it is difficult for the practitioner to have a clear picture of the likely changes in strength over a competitive season in football. In addition, given the duration of the season examined in this study is around half of that typically seen in professional English competitions it is unclear how football players' strength characteristics are likely to change across a much longer competitive season. Furthermore, trends in physical performance over specific periods such as pre-season, the in-season or during congested period when the balance of match frequency and of strength and conditioning may vary substantially, have not been examined.

Finally, despite the known changes in performance as a result of strength training, very little research attention has been given to potential differences in the magnitude of these adaptations reflecting individual player responses in professional sport. Without knowledge of the way in which strength and RFD are likely to change and fluctuate over time, and the potential factors that may influence these changes, it is very difficult for practitioners' to develop optimal prescriptions for the maintenance and development of key physical attributes within football players. Ultimately, to date no published study has monitored measures of isometric force output of professional, senior male footballers over the course of a competition season; hence, the purpose of this study.

Therefore, the aims of this research are as follows:

1. Provide an in-depth analysis of trends in force and RFD production in elite male footballers that have previously not been reported across a competitive season
2. Highlight the differences in both group, sub-group and individual trends that occur across the season that have previously not been reported
3. Highlight the trends in isometric strength performance during different phases of the season as a result of multiple assessment points that have previously not been reported
4. Provide a reliability report on IPC testing in elite football for the first time

Methods

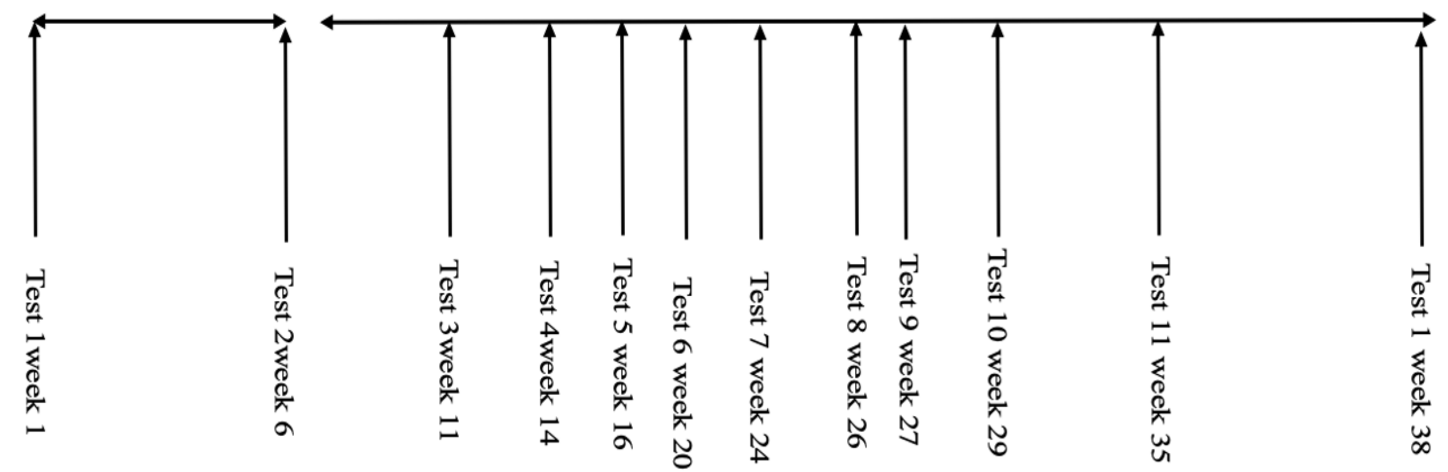
Experimental approach to the problem

The study was designed as a retrospective analysis of data across a full English Championship season. However the 2019-2020 was curtailed prematurely due to the Covid-19 pandemic and the analysis pertains to the first 38weeks (88 % of the season). The pandemic forced a 10-week absence from competition and training, and as such it was not deemed appropriate to include in the analysis data obtained after the returning from the break.

We aimed to quantify changes in variables obtained in the isometric posterior chain (IPC) test (Schache et al 2011; McCall et al ., 2015) performed in a 90:90 position (knee and hip flexion) on a dual force platform sampling at 1000 Hz (Force Decks Lite, Forcedecks, Vald Performance, Queensland, Australia).

Players were tested on 12 separate occasions (T1-T12) over the course of a 38 week season, consisting of a 6 week pre-season phase and a 32 week competitive in-season, consisting of 42 competitive games (figure 1). The first data collection (T1) was on the first day of pre-season training, prior to any other training taking place and following an off-season break. The second data collection (T2) was at the start of the last week of pre-season (34 days later) in the build-up to the first competitive game of the in-season. Data collection sessions 3 – 12 (T3-T12) were taken during the competitive season. For the purposes of the analysis we defined the following sub-phases: Pre-season; Early in-season; congestion period; mid-end in-season. Assessment of performance across the pre-season period is common practice in professional sport, and as such this period was pre-determined by the return to training after an off-season period, and the start of the competitive fixtures. The in-season and congestion period were defined by frequency of match play and S&C sessions (figure 1), with testing occurring in response to the demands of the competitive season.

All tests were performed between 09:45 and 10:30 AM, prior to training and between 24 and 48 hours post-match, with the specific timing influenced by the practical restrictions related to team training and match play schedules. All assessments were conducted by the same practitioner.



	Pre-Season	**In-Season**	**Congestion**	**Mid-End**	**Full Season**
Total days	34	127	77	21	269
Number of matches	6	20	18	4	48
Frequency of match (*days per match*)	5.6	6.3	4.2	5.2	5.6
Number of S&C sessions	6	14	4	2	27
Frequency of S&C session (*days per match*)	5.6	9.1	19.2	10.5	9.9

Figure 1. Schematic representation of the season phases as defined by total number of days; number of matches; frequency of match play; number of S&C sessions; and frequency of S&C sessions.

Note Pre-season phase contained 6 non-competitive matches. Mid-end in-season period was curtailed prematurely due to the Covid-19 pandemic.

Participants

Players were tested periodically with the aim of monitoring their response to a periodised S&C programme implemented throughout the season, running concurrently with a training and match schedule. All players within the senior First Team squad were tested, but goalkeepers were excluded from present analysis due to differences in training and match demands. We also excluded any player who did not complete both T1 and T12, players who were transferred into or out of the club during this period. In addition, test data was excluded if a player had pre-existing conditions or injuries that could affect test performance and /or experienced lower limb muscle soreness or pain before or during testing.

In total, 18 players met the inclusion criteria and were included in the final overall analysis. Player characteristics can be seen in table 1.

Table 1: Player Characteristics

Subject numbers	18
Age (years)	26.43 ± 3.1
Height (cm)	184.33 ± 4.6
Weight (kg)	84.34 ± 7.1

With testing procedures in place prior to the study commencing, consent was provided by the players. The project was approved by the club's sports science department in agreement with the Faculty of Life Science & Education ethics committee, University of South Wales (ethics number 200802LR). All data was collected in accordance with the Declaration of Helsinki 1964

Strength and Conditioning Programme

The nature of the strength training programme was dependant on the training and match schedule, and was designed to develop the physical qualities required to perform for a full season. Strength training programmes were prescribed to the group, with individual variations based on athletes' physical limitations, positional requirements, injury history, exercise preferences, and training history. Example of sessions are highlighted in figures 2 – 4.

All training sessions were designed and supervised by the same qualified accredited strength and conditioning coach (ASCC), to ensure consistency of technique, coaching, encouragement and exercise sequence.

Strength training utilized free weights and was based on modified combination of multi-joint strength and power exercises. Sessions typically included 4 – 6 exercises such as bi-lateral strength (e.g. trap bar deadlift, hip thrusts, RDLs), uni-lateral strength (e.g. rear foot elevated split squats, single leg RDL, multidirectional lunges); power exercises (e.g. loaded and unloaded jumps) and eccentric exercises (e.g. hamstring slide outs and adductor slide outs). Strength exercises were performed as stand alone or in combination with a plyometric similar plyometric exercise. The repetition range for strength exercises was typically moderate - low (4 -6); assistant exercises moderate – high (6 – 12); power exercises low (3 -4). However, exercises had a variable intensity and load depending on the overall schedule and if there was a required emphasis on either force or RFD enhancement. As an example, exercises that emphasised RFD involvement were loaded trap bar jumps, explosive step-ups and derivatives of Olympic weightlifting movements such as a push jerk, or power clean. In addition, strength exercises were encourage to be lifted with maximal speed intent.

Table 2. Example strength and conditioning session during the pre-season phase.

Strength and Conditioning session during pre-season period			
Exercise	**Week 1**	**Week 2**	**Week 5**
Trap Bar Deadlift	2 x 8	3 x 8	3 x 6
Rear Foot Elevated Split Squat	2 x 8	3 x 8	3 x 6
Hip Thrust	2 x 8	3 x 8	3 x 6
Single leg hamstring bridge	2 x 50 % MCT	2 x 75 % MCT	
Single leg calf raises	2 x 50 % MCT	2 x 75 % MCT	
Hamstring eccentric slide outs		2 x 6	3 x 6
Copenhagen Adductor Holds		2 x 10 sec e/l	4 x 15 sec e /l

Note: Sets x Repetitions; MCT – muscle capacity test; e/l – each leg

Table 3. Example strength and conditioning session during the early in-season phase

Strength and Conditioning session during in-season period			
Exercise	**Week 14**	**Week 16**	**Week 22**
Trap Bar Deadlift	4 x 6	3 x 6	
Rear Foot Elevated Split Squat	4 x 6	3 x 6	
Hip Thrust	4 x 6		
Barbell RDL		3 x 6	3 x 6
Single leg hamstring bridge	2 x 50% MCT		
Loaded Single leg calf raises	3 x 12		
Hamstring eccentric slide outs		3 x 6	3 x 6
Copenhagen Adductor Holds			
Explosive step up			3 x 4 e/l
Trap bar jumps			3 x 3
Box Jumps			3 x 4

Note: RDL – Romanian deadlift. Variety of exercises used across the 14 sessions, with individual exercises for players where appropriate.

Table 4. Example strength and conditioning session during the congested phase.

Strength and Conditioning session during congested period		
Exercise	**Week 26**	**Week 31**
Trap Bar Deadlift	3 x 6	2 – 3 x 6
Explosive step up	3 x 4 e/l	2 – 3 x 4 e/l
Single leg DB RDL	3 x 6 e/l	2 x 6 e/l
Adductor Slide Outs	3 x 8 e/l	2 x 8 e/l

Note: RDL – Romanian deadlift; e/l – each leg

Procedures

The IPC test was performed using a portable force platform (FD Lites, Forcedecks, Vald Performance, Queensland, Australia) and Forcedecks software (Version 2.0.7075, Vald Performance, Queensland, Australia). Data was collected at a sampling frequency of 1000Hz.

Reliability of IPC assessment

The IPC testing procedure has been previously described and reported to be reliable (McCall et al., 2015). Prior to the data capture we implemented two reliability evaluations of the mean and peak force in subsamples of players. Thresholds the interclass corelations coefficient (ICC) values were as follows: <0.5 demonstrate poor reliability, ICC between 0.5 and 0.75 show moderate reliability and ICC values between 0.75 and 0.90 demonstrate high reliability, with greater than 0.95 being a gold standard measure (Portney & Watkins, 2000). The first analysis involved testing eight footballers on two consecutive days (between-day reliability) .

The reliability for dominant limb peak force was good (ICC = 0.85) and mean force was moderate (ICC = 0.76). Non dominant peak force (ICC = 0.4) and mean force (ICC = 0.85) were reported as poor and good respectively. The second evaluation involved six footballers repeating the test over two consecutive weeks (between-week reliability), and the same proximity to match play (MD + 2). Dominant limb peak force and mean force had high reliability (ICC = 0.90). Non dominant leg peak force (ICC= 0.81) and mean force (ICC = 0.87) was reported as good. In addition, dominant limb RFD_{100} and RFD_{200} showed moderate reliability (ICC = 0.6 and 0.6), whereas non-dominant limb RFD_{100} and RFD_{200} showed high reliability (ICC = 0.8 and 0.9).

IPC monitoring procedure

The IPC assessment used throughout the season follows a standardised procedure. Players performed a warm up of 5 double leg, 5 unilateral hamstring bridges and isometric efforts of progressive intensity prior to each trial. Prior to each trial commencing, the force plates were zeroed to prevent any inherent noise skewing results. Participants lay supine, facing a box on which the force platform was rested (Figure 2.). The testing limb was positioned at 90° knee and hip flexion using a goniometer, with the heel rested on the force platform and the non-working limb extended alongside the box. To ensure this position for all participants, the height of the box was adjusted accordingly, with a standardised box height of 12” with 3” additional increments provided if required. On the call of “3,2,1, push”, participants performed a 3 second maximal voluntary contraction (MVC) by driving their heel down into the platform. Participants were instructed to keep their arms across the chest, with the practitioner applying pressure to the contralateral hip to ensure the buttocks remained fixed to the ground (Figure 2.) as previously described (Schache et al., 2011; McCall et al., 2015). A

30 second rest was permitted between reps for participants to reassume the starting position and limit the influence of fatigue. Any force trace that excessively strayed from the normal table-top shape (see figure 3) was disregarded from the data collection process.

Results for the group response were reported as dominant and non-dominant limbs, described as the athletes preferred kicking leg (van Melick et al., 2017). To assess sub-group and individual responses, IPC force output was adjusted to body mass in order to normalise the data set as previously reported (Constantine et al., 2019). It has been suggested that this is the most common way to account for the direct relationship between body size and strength (Buchheit et al., 2016). IPC force output (measured in Newtons; N) was calculated by summing the mean value of 3 trials on the dominant limb, and the mean value of 3 trials on the non-dominant limb. This value was then divided by body mass to calculate relative IPC output (Newtons per kilogram; N/kg).

For each trial the variables chosen to be assessed for group, sub-group and individual responses were: Peak Force (PF) (highest force produced across the 3 reps); mean Peak Force (PF_{mean}) (mean of peak force from each of the 3 reps); and rate of force development values at 100- (RFD_{100}), and 200 ms (RFD_{200}). These variables were selected for measurement as they have previously been shown to meet the standards for reliability assessment during isometric force testing (Haff, 2015) and supported by our reliability assessment.

Figure 2. Set up and testing procedure of isometric posterior chain test.

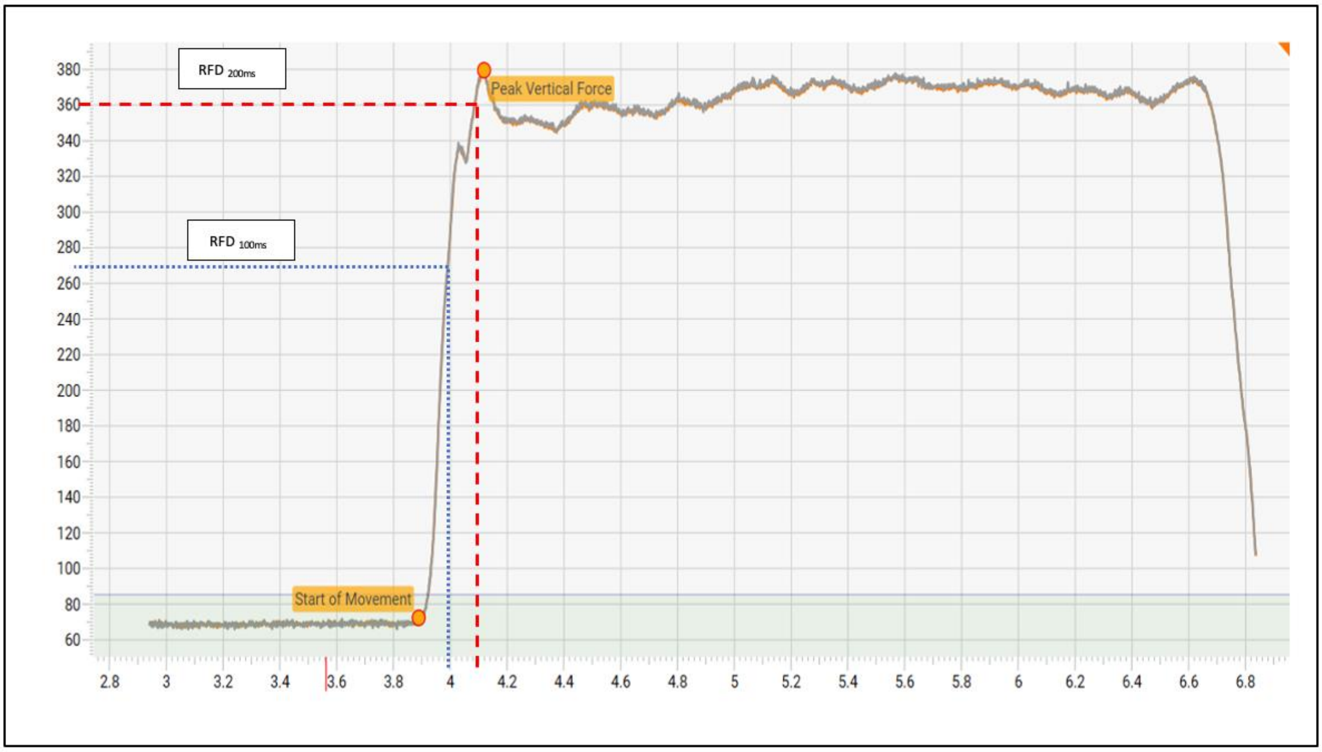


Figure 3. Schematic representation of a force-time graph for assessment of IPC mean, peak force and RFD_{100} and RFD_{200}

Statistical Analysis

Group analysis

A Bayesian linear mixed effect model, with individual intercepts and slopes for participants allowed to vary, was used to determine changes in force time characteristics across the season and between tests. Given prior knowledge of differences in timepoints was unknown, prior knowledge was captured in a weakly informative prior with a normal distribution centred on zero with wide tails for differences and a half student T distribution for standard deviations. Each model was checked for convergence both visually and using $\hat{R}$. Prior predictive checks were employed to check the feasibility of the priors used, and posterior predictive checks used to determine model fit by looking for discrepancies between the distribution of the simulated data from the model and the observed data (Gabry et al., 2019).

Descriptive data for all subject characteristics (height, weight, age etc) presented in the text, figures and tables are given as means ± standard deviation (SD). The results of inferential tests for all force characteristics are reported as estimated marginal means along with the associated 95% Highest Density Intervals (HDIs) as measures of uncertainty in the point estimates. These similar to traditional confidence intervals but can be accurately interpreted as a 95% chance the ‘true’ population difference is contained in the interval. These estimates may differ from descriptive means because they are able take into account the variation across individuals and time points. The probability of direction (%) are also reported for each variable measured, these can be interpreted as the direct probability of an effect - a difference in either direction greater than zero (Makowski et al, 2019).

Using standardised differences (Cohen's *d*) as an effect size measure, the magnitude of the differences in terms of standard deviations between variables (force and RFD) are also reported for the start and end of the season (T1 & T12), and across different phases of the season (e.g. start and end of the pre-season phase). Changes in isometric force and RFD were categorised as trivial (ES <0.0), small (ES <0.2), moderate (ES 0.2-0.5) and large (0.5-0.8) (Cohen, 1988).

Given the recent criticism concerning the use of magnitude-based inferences (Sainani, 2018), we have also included effect estimate and probability of direction associated with each effect. This enables coaches to understand and interpret the results in a manner that suits and is applicable to them.

All statistics were performed using R statistical package (4.0.2, R Core Team, 2020) and the Bayesian Regression Models in Stan package (brms; Bürkner, 2018).

Sub-group and Individual analysis

To examine whether players relative force at the baseline testing determined different magnitudes of adaptations during the season we used a simple median split. This method has previously been used to determine sub-groups in sporting populations (Johnston et al., 2015; Abbott & Clifford, 2021). Analysis resulted in sub-grouping participants into low (*n*= 9) or high (*n*= 9) force producers with respect to their placement above or below the median split for relative peak force (N/kg), relative average peak force, RFD_{100} and RFD_{200} measured at baseline (T1). The use of IPC relative force has previously been used in football players (Constantine et al., 2019) and is described in detail above.

To help determine whether athletes could be classified as a high-, low- or negative-responder, the magnitude of change in individual players IPC output across the whole season was reported as percentage % change relative to baseline. Furthermore, a median split was used to provide further sub-group analysis. Finally, and in addition, magnitude based inferences were then calculated to determine the likelihood of a meaningful effect, with the level of response for each individual athlete based on the reported SWC - which is classified as 0.2 of the baseline between subject standard deviation (Hopkins, 2004). A meaningful increase or decrease in outcome measure (force or RFD) was classified accordingly, with a positive response the result of % change being greater than the SWC.

Results

Group analysis : Full season

The analysis of trends across the full season (T1-T12), showed small to moderate magnitude increases in mean and peak force and RFD_{100} and RFD_{200}, and were possibly beneficial (Table 5, figure 4). Mean force increases were similar in both limbs. The increase in peak force across the season was small in the dominant but moderate in the non-dominant limb. There were small, increases in RFD_{100} and RFD_{200} across the season in both limbs but these changes were greater in the dominant limb than the non-dominant limb. The probability of direction showed a strong chance (92-100%) of an increase in all force and RFD metrics between T1 and T2 (start and end of pre-season).

Table 5: Isometric posterior chain performance metrics (means ± standard deviation) across the season, T1 – T12

	Test 1		Test 12		Effect Size		Probability Direction %	
	Dom	NDom	Dom	NDom	Dom	NDom	Dom	NDom
Mn Force	266± 22	265± 19	287± 23	288± 19	0.47	0.42	100	99.9
Pk Force	282± 23	274± 18	295± 23	296± 19	0.27	0.53	98.9	100
RFD100ms	889±459	799±549	1076±534	933±512	0.38	0.24	95.1	90.5
RFD200ms	766±240	754±218	866±259	817±223	0.39	0.25	98.2	92.6

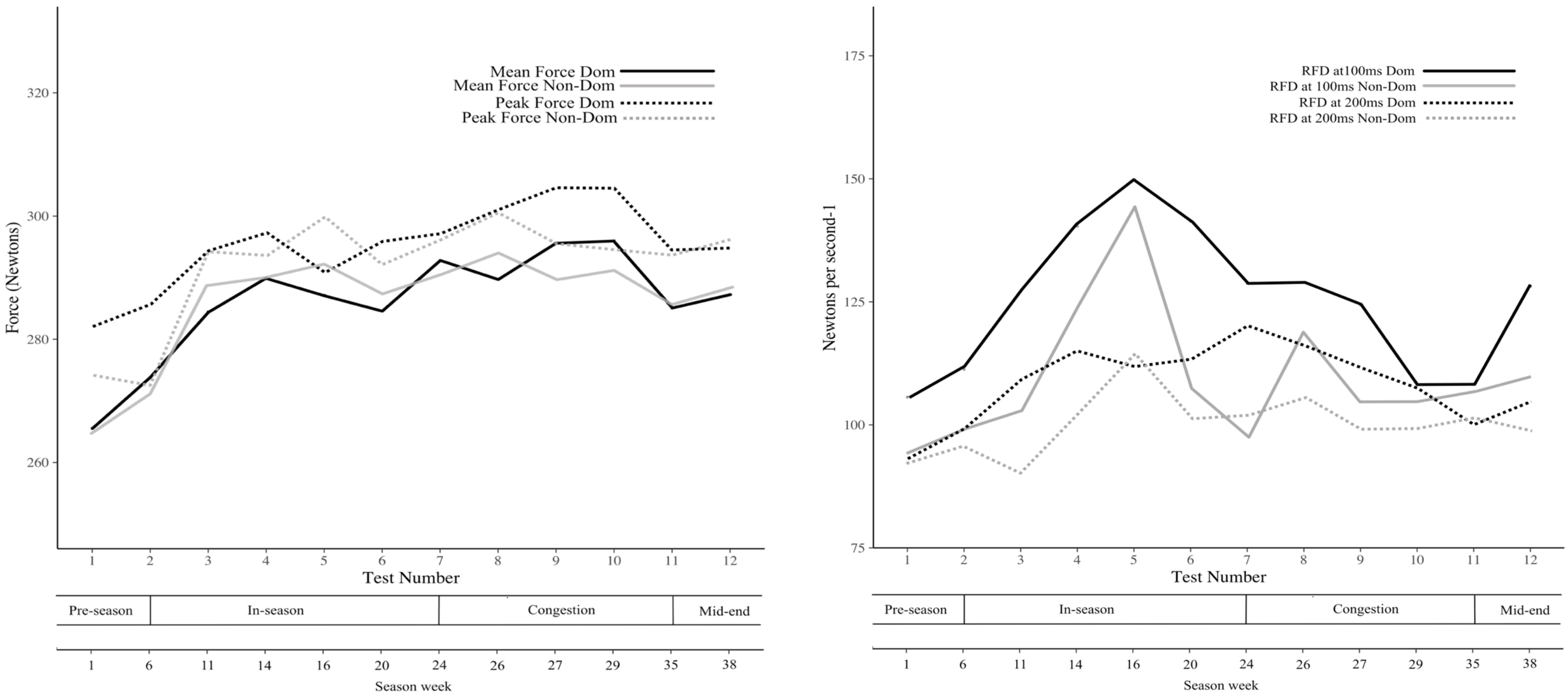


Figure 4. Changes in Isometric Posterior Chain a) mean and max force; and b) RFD_{100} and RFD_{200} across a 38 week football season in dominant and non-dominant limbs.

Pre-Season

Test 1 – Test 2

Across this period non-dominant mean force which displayed a moderate magnitude increase, while all other increases were trivial (Table 6).

Table 6: Posterior chain Isometric force (means ± standard deviation) across the pre-season phase (T1 – T2)

	Test 1		Test 2		Effect Size		Probability Direction %	
	Dom	NDom	Dom	NDom	Dom	NDom	Dom	NDom
Mn Force	266± 22	265± 19	274± 24	271± 22	0.18	0.57	89.3	85.4
Pk Force	282± 23	274± 18	286± 19	272± 26	0.07	0.03	66.4	56.2
RFD100ms	889±459	799±549	908± 533	841± 594	0.03	0.07	56.5	63.5
RFD200ms	766±240	754±218	809± 280	785± 248	0.17	0.12	79.4	74.1

In-Season

Test 2 – Test 7

Across this phase, large magnitude increase was recorded for non-dominant peak force and dominant limb RFD_{200}, with moderate, likely beneficial improvements for all other measures (Table 7).

Table 7: Isometric force performance (means ± standard deviation) across the in-season phase (T2 – T7)

	Test 2		Test 7		Effect Size		Probability Direction %	
	Dom	NDom	Dom	NDom	Dom	NDom	Dom	NDom
Mn Force	274± 24	271± 22	293±23	271±22	0.41	0.46	99.1	99.6
Pk Force	286± 19	272± 26	297±24	296±26	0.25	0.57	90.3	98.5
RFD100ms	908± 533	841± 594	1084±567	829±592	0.35	0.02	90.1	53.4
RFD200ms	809± 280	785± 248	992±272	843±269	0.72	0.25	99.7	82.9

Congestion period

Test 7 – Test 11

Across this period, in the dominant limb there were small to moderate decrease in RFD_{100} and RFD_{200} respectively, and trivial declines in peak and mean force. In the non-dominant limb, there were trivial improvements in non-dominant mean force, RFD_{100} and RFD_{200}, and trivial decreases in peak force (Table 8).

Table 8: Isometric force performance (means ± standard deviation) across the congested fixture period (T8 – T10)

	Test 7		Test 11		Effect Size		Probability Direction %	
	Dom	NDom	Dom	NDom	Dom	NDom	Dom	NDom
Mn Force	293±23	271±22	285±22	286±20	-0.16	0.11	84.7	73.8
Pk Force	297±24	296±26	294±23	294±26	-0.05	-0.05	62.9	61.5
RFD100ms	1084±567	829±592	901±469	924±603	-0.37	0.17	92.2	74.1
RFD200ms	992±272	843±269	818±250	848±268	-0.69	0.01	99.7	52.6

Mid to end of in season period

Test 11 – Test 12

Across this period, there was a small magnitude increase in dominant limb RFD_{100}, and trivial improvements for all other measures (Table 9).

Table 9: Isometric force performance (means ± standard deviation) across the mid-end season period (T11 – T12)

	Test 11		Test 12		Effect Size		Probability Direction %	
	Dom	NDom	Dom	NDom	Dom	NDom	Dom	NDom
Mn Force	285±22	286±20	287±23	288±19	0.04	0.06	61.6	65.7
Pk Force	294±23	294±26	295±23	296±19	0.002	0.05	50.7	63.4
RFD100ms	901±469	924±603	1076±534	933±512	0.35	0.01	93.4	51.9
RFD200ms	818±250	848±268	866±259	817±223	0.19	0.13	81.8	71.5

Sub- group and Individual Analysis

Table 10 shows IPC force output for each player with the group dichotomised to low (*n*= 9) or high (*n*= 9) strength based on a medium split of baseline (T1) relative force and RFD**.** Table 11 shows the magnitude of change (as percentage % change relative to baseline) in individual players IPC output, across the whole season (T1- T12). In addition, table 11 highlights the sub-groups of low and HB-strength, whereby the lowest (*n*= 9) and highest force producers (*n*= 9) are denoted for each force characteristic. Figure 5 shows scatter plots of individual players change in a) mean force, b) peak force, c) RFD_{100} and d) RFD_{200} based on low and high force output groupings between the start (T1) and end (T12) of the season. Figure 6 shows changes in force production characteristics across phases of the season for players above or below the median split at T1 testing. Figure 7 shows individual players peak force and mean force outputs for all tests across the season. Figure 8 shows individual players RFD_{100} and RFD_{200} outputs for all tests across the season.

Table 10. Median split of the group to categorise athletes as low or high IPC relative force producers dichotomised according to baseline (T1) values.

	Mean Force		Peak Force		RFD 100ms		RFD 200ms	
	Athlete ID	Relative score (bw.kg)	Athlete ID	Relative score (bw.kg)	Athlete ID	Relative score (bw.kg)	Athlete ID	Relative score (bw.kg)
Low (*n*= 9)	14	4.2	14	4.6	14	6.7	14	10.5
	8	4.9	8	5.2	12	7.4	12	11.5
	6	5.6	12	5.9	16	8.5	8	13.2
	1	5.7	1	6.1	8	10.8	1	13.4
	12	5.7	6	6.2	1	12.1	16	14.9
	7	6.1	7	6.4	7	13.4	9	15.2
	2	6.2	2	6.4	18	14.3	4	15.5
	4	6.2	15	6.6	6	16.1	2	17.2
	9	6.3	18	6.6	9	16.4	6	17.6
High (*n*= 9)	15	6.4	9	6.7	4	17.0	7	17.7
	18	6.4	13	6.7	2	21.6	18	18.0
	13	6.5	16	6.8	5	21.8	13	18.7
	16	6.6	4	6.8	13	25.9	11	19.9
	11	7.0	17	7.1	11	27.0	15	21.9
	17	7.0	3	7.2	15	28.5	5	22.0
	3	7.0	11	7.3	3	29.9	17	22.1
	5	7.6	5	8.0	17	34.6	3	27.2
	10	7.7	10	8.0	10	43.7	10	27.3

Table 11. Individual athlete all force and RFD isometric posterior chain performance metrics across the season, T1 – T12

	Mean Force, N			Peak Force, N			RFD-100ms			RFD 200ms		
Athlete ID	T1	T12	% change	T1	T12	% change	T1	T12	% change	T1	T12	% change
1	5.7	6.4	10.7	6.1	6.5	7.3	12.1	21.3	75.7	13.4	17.5	30.1
2	6.2	6.2	0.8	6.4	6.4	1.4	21.6	30.0	38.9	17.2	19.6	14.2
3	7.0	7.3	3.9	7.2	7.5	3.0	29.9	30.2	0.9	27.2	26.4	-3.0
4	6.2	7.3	16.3	6.8	7.3	6.8	17.0	39.3	131.5	15.5	25.2	62.2
5	7.6	7.3	-3.9	8.0	7.5	-7.0	21.8	25.7	17.8	22.0	21.5	-2.0
6	5.6	6.9	24.7	6.2	6.9	12.8	16.1	16.8	4.7	17.6	15.6	-11.1
7	6.1	6.5	6.3	6.4	6.7	4.5	13.4	13.2	-1.3	17.7	18.6	4.9
8	4.9	6.4	29.7	5.2	6.5	26.7	10.8	19.4	79.5	13.2	17.5	32.6
9	6.3	6.2	-1.4	6.7	6.7	0.2	16.4	11.8	-28.3	15.2	13.2	-13.2
10	7.7	8.1	4.7	8.0	8.3	4.0	43.7	35.0	-20.0	27.3	25.1	-8.3
11	7.0	7.3	3.9	7.3	7.5	3.1	27.0	27.3	1.2	19.9	22.5	12.9
12	5.7	6.0	5.1	5.9	6.2	5.2	7.4	8.7	16.8	11.5	10.1	-12.5
13	6.5	7.1	8.3	6.7	7.2	7.3	25.9	33.5	29.0	18.7	23.2	24.5
14	4.2	5.6	35.3	4.6	5.7	23.1	6.7	15.2	124.9	10.5	16.7	59.2
15	6.4	6.8	6.8	6.6	7.1	8.7	28.5	26.0	-8.8	21.9	24.1	10.2
16	6.6	7.9	18.8	6.8	8.0	18.4	8.5	20.2	138.2	14.9	24.4	63.9
17	7.0	7.3	4.9	7.1	7.4	4.3	34.6	40.0	15.8	22.1	24.4	10.5
18	6.4	6.5	1.2	6.6	6.6	-0.9	14.3	10.5	-26.6	18.0	12.8	-29.0
mean			9.78			7.12			32.77			13.67
Std. Dev			10.9			8.42			54.19			27.26
SWC			2.18			1.68			10.83			5.45
CV%			1.08			1.14			1.6			1.93

Note: Non-shaded cells denotes players in low force output sub-group; Light grey shaded cells denotes players in high force output sub-group.

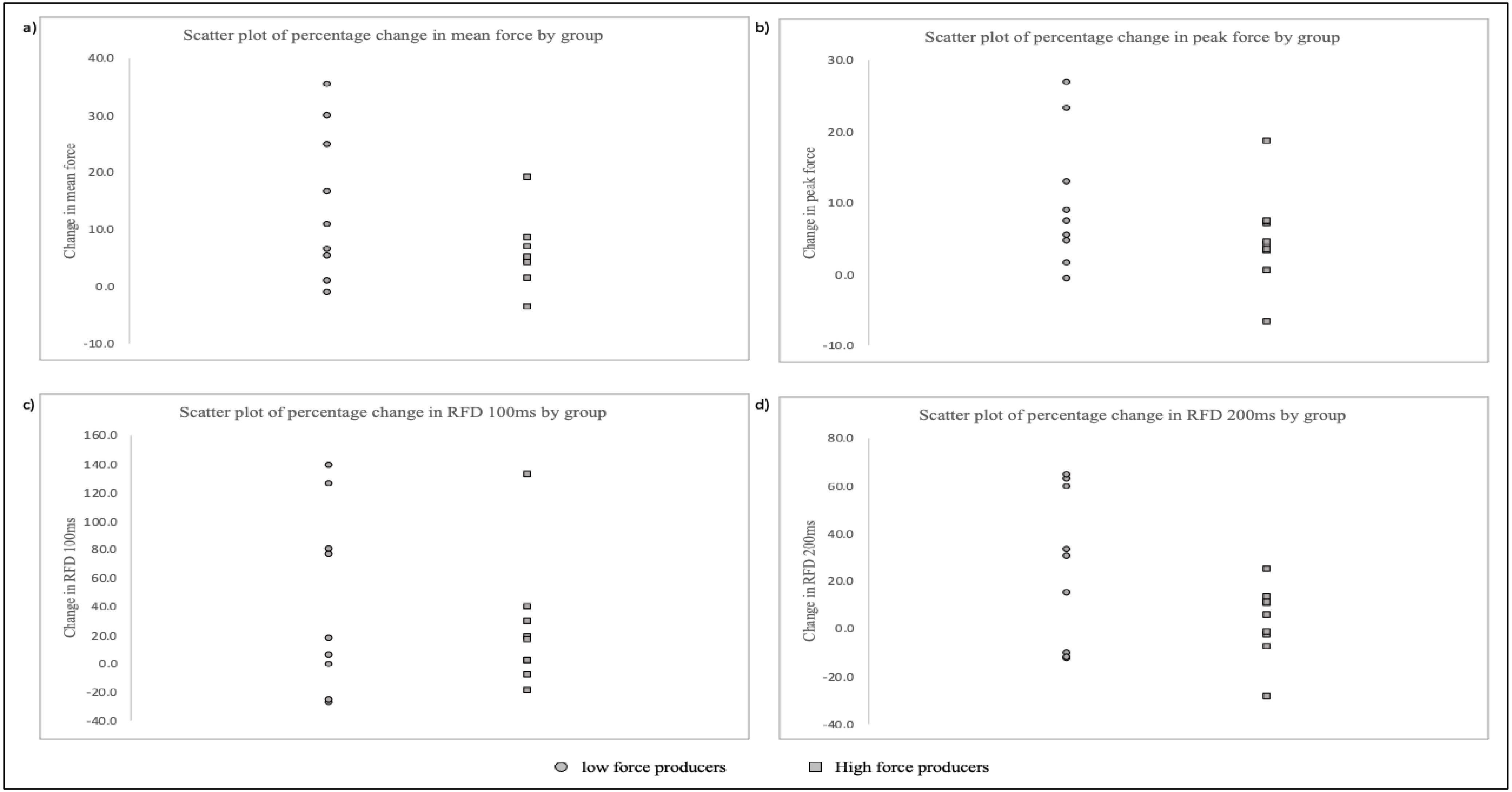


Figure 5. Scatter plots of individual players change in a) mean force, b) peak force, c) RFD_{100} and d) RFD_{200} based on low or high force output groups between the start (T1) and end (T12) of the season

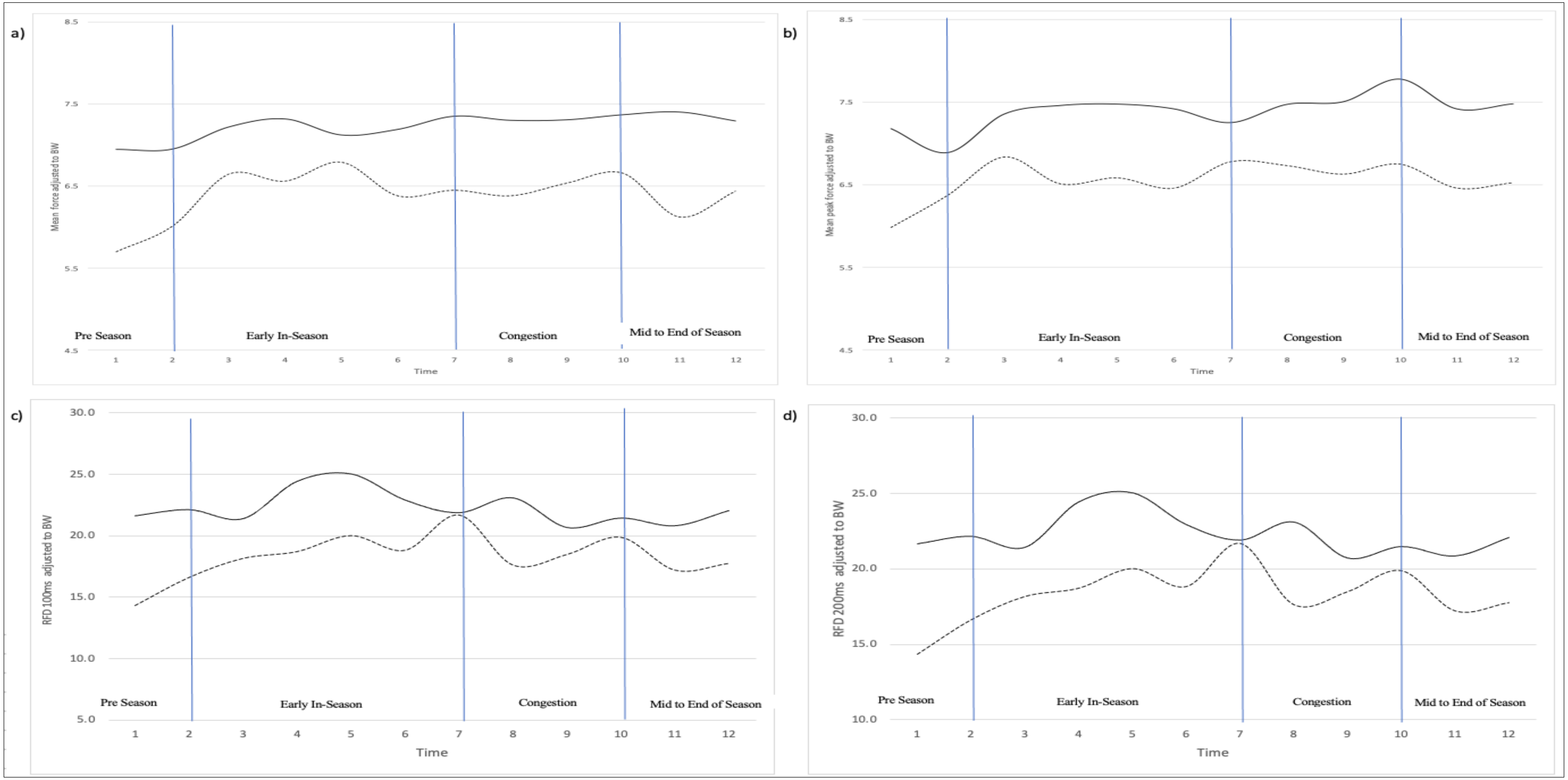


Figure 6. Changes in a) mean isometric force, b) peak isometric force, c) RFD_{100} and d) RFD_{200} across the phases of the season for players above or below the median split at T1 testing . ----- low force output; —— high force output.

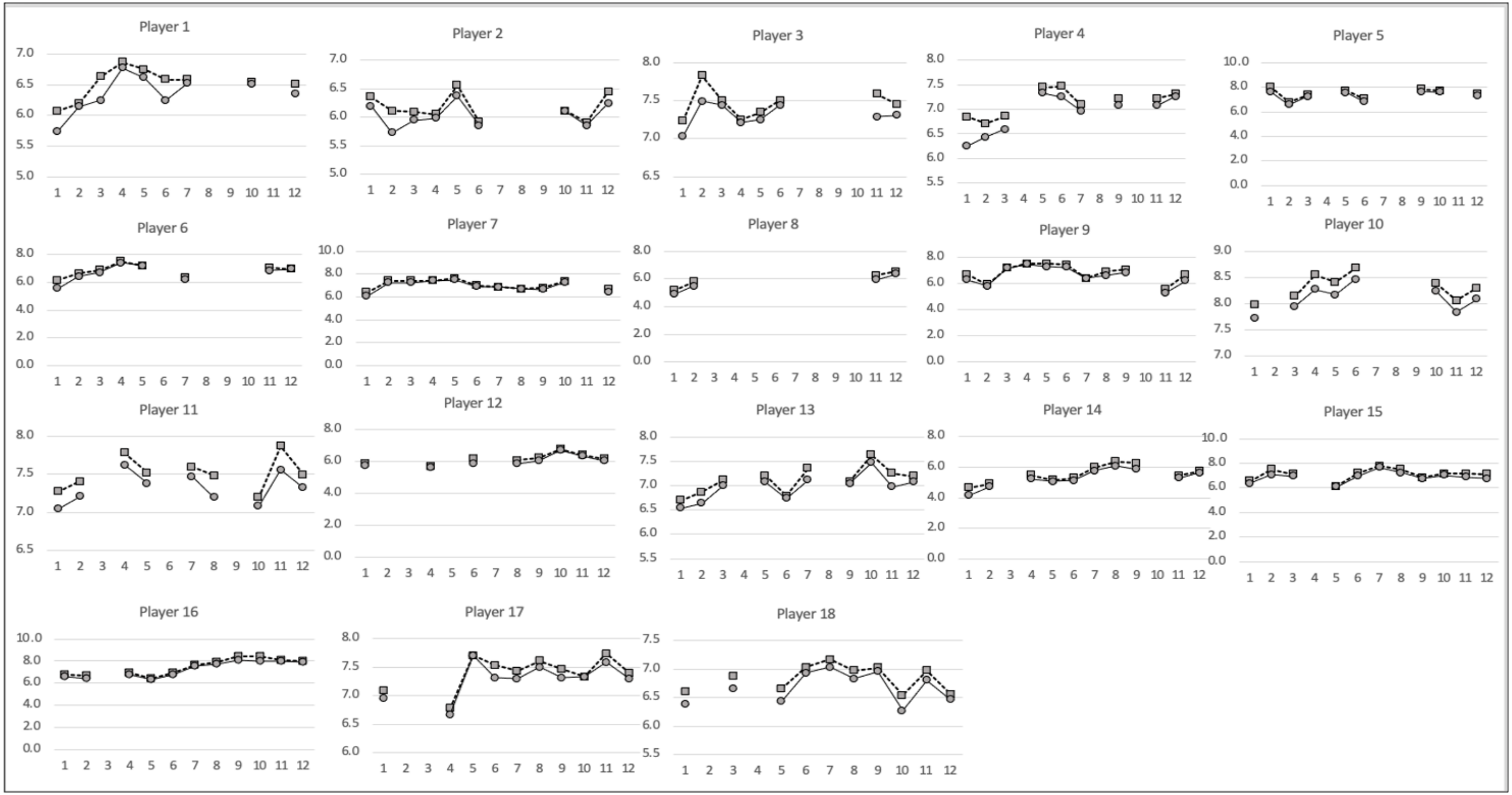


Figure 7. Individual players peak force and mean force outputs (relative to body weight) for all recorded tests across the season. (▢ peak force: ○ mean force)

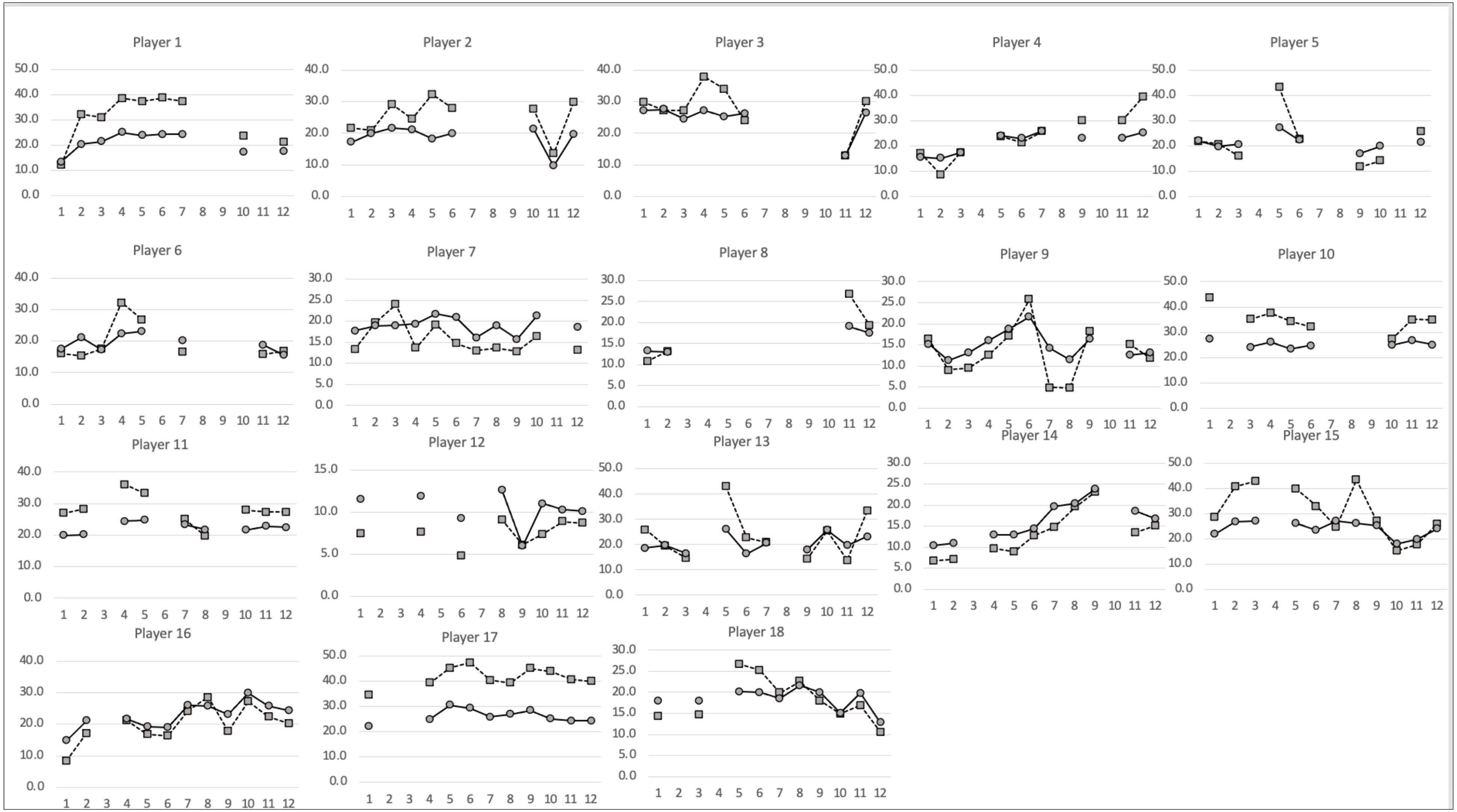


Figure 8. Individual players RFD_{100} and RFD_{200} outputs (relative to body weight) for all recorded tests across the season. (◼ RFD_{100}: ● RFD_{200})

Discussion

The primary aim of this investigation was to examine whether posterior chain isometric force characteristics changed over the course of a whole season in elite football. In addition, in an attempt to understand the effect of specific match : strength training ratios on changes in isometric force output we also analysed specific phases of the season.

Furthermore, we aimed to provide trend analysis of seasonal force output in two sub-groups; those who are classified as either low or high force producers based on baseline testing (T1). Lastly, we described the magnitude of individual athlete changes in isometric force performance over the course of the season; not previously reported in professional football players before.

We found small to moderate improvements (ES range 0.27 – 0.53) and a 98.9 - 100% chance of an increase peak isometric force between T1 and T12. In addition, there was a small improvement (ES = 0.24 – 0.39) and a 90.5 – 98.2% chance of increase in RFD in the same period. With specific reference to the specific sub-phases of the seasons; pre-season, early in-season, congested and mid-end of season phases, the early in-season period of the competitive season demonstrated the largest increase in peak force output. This phase was characterised by an increased exposure to S&C training (1 sessions per 9.1 days) and a reduced match frequency (1 match per 6.3 days) when compared to other phases of the season. These results may therefore suggest that periods of less match play density and greater S&C density contribute to the large positive changes in isometric force output. This trend is further highlighted by the reduction in mean and peak force seen during the congested period of the season where fixture density was highest, and S&C exposure was at its lowest. However, despite showing a drop off in isometric force during the congestion period in relation to the previous period, mean and max peak force remained above baseline measures (T1) and end of pre-season (T2). This may suggest that improving force production capabilities of professional football players during the early phases of a season can help maintain performance during periods traditionally viewed as detrimental to physical performance. In addition, results from this study highlight, for the first time, that training with the aim of improving lower limb strength across the duration of a full season, rather than the often suggested training for maintenance of strength (Turner and Stewart, 2014) is achievable during the concurrent nature of a professional football season.

This investigation also sought to examine sub-group and individual responses of players in addition to the group mean over the whole season. To examine whether players relative force at the baseline testing determined different magnitudes of adaptations during the season, this study used a median split to sub-divide the players into high- and low- force groups. At the end of the season, the lower-force group showed a trend towards a greater positive adaptation in mean and peak force, as well as RFD_{100} and RFD_{200}. However, the high-force group showed less variability across the season, with less overall improvement, but also less decline during the congested period where match frequency was high and S&C input was lower than other phases. Recently, it has been shown that when accounting for baseline strength, elite athletes with lower starting strength showed a greater capacity for IMTP: peak force improvements (Norris et al., 2021) across a season. In addition, it was shown that higher baseline strength may improve match related responses in neuromuscular function (Norris et al., 2021).

Finally, individual analysis of trends suggest that there is a varying magnitude of individual change (as expressed by % change from T1 to T12). In addition, it can be seen that an individual who expresses a large change in one measure, e.g. peak isometric force, may express a small or even negative change in another measure, e.g. RFD_{100} (see athlete 5 for example).

To date no published study has monitored isometric force profiles of elite football players over the course of a competition season; hence, the purpose of this study. The results from this investigation suggest for the first time, that isometric force and RFD characteristics can be improved across the duration of a competitive season in professional football players. This contrasts with the opinion where the outcome of in-season interventions are often maintenance or reductions, not improvement of strength output during a season. In addition, this highlights the need for the practitioner to understand different training stimuli may be required to achieve positive adaptions for all players, as its shown that players can experience a high, low or negative responses to the training stimulus.

Changes in force-time characteristics over the course of the season: group response

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Peak & Mean Isometric force : overall trend

While most studies measuring neuromuscular strength changes within sport have examined maximal strength using isokinetic dynamometry (Aagaard et al., 2002; Jones et al., 2020), repetition maximum of the half squat (Rønnestad et al., 2011) , IMTP (Norris et al., 2021; Comfort et al., 2020; Emmonds et al., 2018) this is the first to report peak and mean force output using an IPC measure. The use of isometric testing has previously been found to be highly related to dynamic performance (Haff et al., 2005; Stone et al., 2004) and thus can be applicable to sporting actions. The specific use of the IPC-test has previously only be used to highlight levels of match-related fatigue (Constantine et al., 2019; Nedelec et al., 2014; Matinlauri et al., 2019) and not changes in isometric force across any considerable period of time.

In this investigation increases in both isometric peak and mean force were observed over the duration of a season. Increases of 4.6% and 8.02% (dominant and non-dominant limb respectively) in IPC peak force were observed from T1 to T12 across the season. A very similar pattern was observed for IPC mean force, albeit mean force in the dominant limb showed a 7.8% increase. Interestingly, while increases in mean force were of similar magnitude in both limb (dominant limb ES = 0.47; non-dominant limb ES = 0.42;) peak force changes were substantially higher in the non-dominant (ES = 0.53) than the dominant (ES = 0.27) limb.

From pre- and early in-season, both mean and peak force steadily increased throughout the in-season phase, reaching their highest values at T9 in the dominant limb, and T5 in the non-dominant limb. As this is the first study which describes changes in isometric force production capacity in professional footballers during a full competitive playing season, there is no data which with to directly compare our findings. The 90:90 supine IPC test has principally been used in football to quantify match induced short-term fatigue and subsequent recovery cycles (Constantine et al., 2019; Nedelec et al., 2014; Matinlauri et al., 2019), or during rehabilitation during return to play (Tabener et al., 2018). However, examining data from these studies, values for IPC- peak force in the present cohort are comparable with those reported. For example, the highest peak force recorded in this study (305 - 301N dominant vs non-dominant limb) compare favourably to those reported in Spanish semi-professionals (284 – 289 N) (Matinlauri et al., 2019), and during hamstring rehabilitation in a Premier League footballer (312 – 317 N) (Taberner et al., 2018). However, while comparisons of data is useful, the differences in methodology and context are apparent. The IPC testing procedure in the Matinlauri et al., (2019) study was recorded in semi-professional players, prior to a match-simulation protocol. All the tests in this investigation were taken +24 – 72 hours post-match, and on professional footballers. In addition, the lack of acute and chronic match related fatigue are also not factored into the end stage rehabilitation seen in the Taberner et al., (2018) study, and was only obtained from one individual, whereas our data is a group response mean.

While there is a lack of comparative seasonal strength trend data in senior professional football, the season-long improvements observed align in terms of the magnitude of change, with that reported in isometric squat peak force across a 45 week season in elite Rugby Union (ES = 0.32 – 0.5) (Gannon et al., 2015; Appleby et al., 2012). Evidence from these studies also indicated that strength and power can be improved with concurrent conditioning during a competition period (Gannon et al., 2015; McMaster et al., 2013; Appleby et al., 2012). Research in different codes of rugby suggests that it is possible to improve lower body maximal strength over a competitive season providing between 2 and 3 resistance training sessions are performed each week (Argus et al., 2010). In the current analysis, players participated in a maximum of one strength training session per week. The structure of the training week and fixture scheduling in football do not often allow for 2 to 3 sessions per week for consistent periods of the season. In fact most practitioners' in elite football provide 1 – 2 lower limb sessions per week to their players (Beere et al., 2020, project 1a). The results from this current investigation progresses and challenges the often cited findings by Rønnestad et al., (2011). Rønnestad et al., (2011) reported the maintenance of strength during the first 12 weeks of an in-season phase as a result of strength training once per week in elite footballers, whereas our data suggest one session can improve force capabilities. This work is often cited as evidence for strength training programmes in elite football environments.

However, we believe that as a result of our findings, this opinion should be challenged with the notion that strength can be improved across the season in professional footballers.

While the finding that there was an overall trend from pre-to post season is of interest, understanding the trends in IPC force-time across specific phases of the season in response to concurrent strength training and match play could be of value to practitioners'.
The analysis of isometric peak force and RFD highlights how these characteristics differ across specific periods of the season. While we cannot attribute all variations in isometric force to S&C frequency and volume, and that match-play may provide a stimulus for neuromuscular adaptation (Morgans et al., 2018), a pattern is evident whereby increased isometric force output follows periods of high S&C input and reduced match- play.

Peak & Mean Isometric force : pre-season

Given that preseason is considered to be the principle opportunity for physical preparation in team sports (Argus et al., 2009; Comfort et al., 2012) due to fewer competitive games, our finding that during that 5-week period (T1-T2) there were only trivial increases in force, and in fact a small decrease in non-dominant limb peak force, was somewhat contrary to expectations. An increase of 1.4% (dominant limb) and a decrease of 0.74% (non-dominant limb) in IPC peak force were observed from T1 to T2 across the pre-season. Changes in mean force were slightly greater (3 and 2.2% dominant and non-dominant respectively) across this period. As well as the lower percentage change and lower magnitude of change as represent by effect sizes, peak force also showed a considerably lower probability of direction change when compared to mean force (56.2-66.4% vs. 85.4-89.3%).

Indeed, this contrasts with evidence in professional football (Helgerud et al., 2011) and rugby union athletes (Gannon et al., 2016; Argus et al., 2010) that demonstrate significant/magnitude improvements in measures of lower body strength in pre-season. Helgerud et al., (2011) highlighted an average 52% increase in back squat strength over the 8 week pre-season period which included 16 strength based training sessions. In rugby union, Gannon et al., (2016) demonstrated a small increase in force output (+2.7% increase, ES = 0.21) (albeit the largest of any phase of the season), and a very likely beneficial improvements in RFD 100-ms after a 12 week pre-season phase (+13.9%, ES 0.63). This greater total volume of sessions, and longer pre-season phase compared to that used in this investigation may explain more substantial increases in strength than in this group. . This would concur with previous research showing that frequency and volume are key variables in bringing about positive adaptations within maximal strength (Peterson, Rhea and Alvar, 2005).

In this investigation, the team's pre-season was 34 days, which is typical of this football club (as seen in project 2) and of many football teams (Ekstrand et al., 2020) but shorter than the 8 weeks reported in previous football research (Helgerud et al., 2011) and 12 weeks in Rugby (Gannon et al., 2016) where larger improvements in strength and power have previously been shown during this phase. The structure of a standard football pre-season may not be optimal for large increases in force development (Jones et al., 2013). Training volume / load can often be higher during pre-season than the in-season period. Professional teams typically perform 4-6 training sessions per week during the competitive season (Bangsbo et al., 2006) depending of fixture schedules. However, this training load can be as high as 1-2 sessions, 5-6 days a week during pre-season (Impellizzeri et al., 2006). Such changes in the training programme therefore dramatically increase the training demands placed on players and may result in differences in the physiological stress associated with this work (Goto et al., 2007; Ronsen et al., 2001; Stich et al., 2000). In this investigation, players trained five to six days a week, including 6 non-competitive matches during the pre- season training phase. During this phase, the emphasis of physical training programmes are centred towards aerobic and mixed aerobic- anaerobic running activities, as well as the technical drills and team tactics. In addition, players participated in only 6 S&C sessions (1 session per 5.7days) and 6 non-competitive matches (1 session per 5.7 days). The high volume of pitch based conditioning work, and the limited S&C input, may explain the trivial increases in force production observed. The accumulation of high levels of fatigue may contribute to the lack of improvements in maximal force outputs. In addition, it could also be noted that the S&C programme during the pre-season phase contained lower load than in later periods of the season due to the progression criteria of establishing movement competency and the principle of progressive overload required to prevent risk of injury and DOMS. The pre-season programme focussed on building muscle tissue tolerance and progressive increases the volume and intensity of the sessions. The pre-season phase follows the off-season during which time a decline in some physical qualities often takes place, such as maximal strength (Argus et al., 2012). Whilst subjects were given off-season training plans, the reduced volume, loading and unsupervised nature of training within this period means detraining is likely. It is therefore possible that the albeit small increases in strength during the pre-season are largely a return to previous levels.

Interestingly, the magnitude of change differed across the variables assessed. For example, in the non-dominant limb, mean force shows a 2.2% change, with a large effect size (0.57) across the pre-season phase. However, there is a decrease of 0.74% , with only a trivial effect size of 0.03 in peak force for the same limb. Based on this variation in response and magnitude of change, it may be sensible for practitioners’ to monitor both mean and peak force. This would allow a greater understanding of an athletes response to overall training load.

Peak & Mean Isometric force : early in-season

While force output was significantly higher at the end (T12) compared to the beginning of the season (T1), the largest increase in peak force output was observed during the in-season phase between T2 and T7. The probability of direction across mean and peak force shows that there is a 90.3 – 99.6% change of a positive change within the group during this phase. During this early in-season period, 14 S&C sessions were undertaken at a rate of one per 9.1 days. This is in-comparison to the 19.2 days during the congestion phase, and 10.5 days during the mid-end season. The increased S&C exposure during the early in-season phase is coupled with a reduced match frequency compared to the other in-season periods (one match per 6.3 days vs. 4.2 and 5.2 days in the early- congested – and mid-end season phases respectively) (see figure 1). As it has been shown that frequency and volume are key variables in bringing about positive adaptations within maximal strength (Lauersen et al., 2018; Peterson, Rhea and Alvar, 2005), it is likely that the greater increases in peak force output in the early in-season phase compared to other phases of the in-season were due to the greater frequency and higher total volume of resistance training performed within this phase (see figure 1),

Interestingly, while increases in mean force were of similar magnitude in both limb (dominant limb ES = 0.41; non-dominant limb ES = 0.46;) peak force changes were higher in the non-dominant (ES = 0.57) than the dominant (ES = 0.25) limb during the in-season phase. The continual trend showing non-dominant peak force being greater than dominant limb is interesting as it could be expected that the dominant limb is stronger as a result of more frequent ball striking or take-off during a jump. However, the definition of limb dominance can be questioned (Virgile & Bishop et al., 2021). In this study, limb dominance was defined as the players preferred kicking limb. It is easy to suggest that limb dominance is the athletes preferred kicking limb, however, limb dominance could be task dependant and even change across the course of the season (Virgile & Bishop et al., 2021) and thus the preferred kicking limb may not be force dominant in certain tasks.

Peak & Mean Isometric force : congested period trend

It is well known that football schedules are often congested, chaotic and at constant threat of changing due to several factors such as television coverage and progression in one or a number of knockout tournaments. Issues around fixture congestion are impossible to change, as the nature of the sport can require teams to play 2-3 games per week for the vast majority of the season (Anderson et al., 2015; Thorpe et al., 2016). This is the case for not only the elite teams playing in European competition, but also those in English domestic leagues, due to involvement in multiple cup competitions on top of a 38-46 game league season. It becomes difficult to periodise, manage training load and avoid accumulated fatigue, while ensuring that players remain at an optimal level of physical fitness during the season (Anderson et al., 2015). Fixture congestion can be defined as a minimum of two successive bouts of match-play separated by <96 hours and is a frequent and contemporary issue in professional football (Jullian et al., 2021). Congested fixture periods can be associated with reductions in performance and increased rates of muscle injury (Carling et al., 2016; Dupont et al., 2010), with the hamstrings being the most commonly injured muscle during these periods (Carling et al., 2016).

Match frequency during the congestion period was higher than any other period (18 matches in 77 days; mean of 1 game/ 4.28 days) and S&C sessions were at lower than any other period across the season (4 sessions in 77 days; mean one session/ 19.25 days) (figure 1). It is therefore not surprising that this phase resulted in small decreases in mean and peak isometric force from the previous period (see table 8). Interestingly, despite showing a drop off in isometric force during the congestion period in relation to the previous period, mean and max peak force remained above baseline measures (T1) and end of pre-season (T2).

It should also be noted that the highest mean and peak force outputs for the season were recorded during this period; dominant limb (T9 or T10) and non-dominant limb (T8). This is potentially somewhat surprising given the high density of competitive matches and reduced recovery time during this period. However, it could be suggested that the occasionally higher levels of force output even during the congestion period may in part be due to the timing of the IPC-test in relation to the match, the players who were tested (as not all players were assessed on every test) or the potential positive adaptation to competition stimulus (Morgans et al., 2018). All the tests in this investigation were taken +24 – 72 hours post-match, where the likelihood of match related fatigue could have contributed to the reduced force output in those tests taken only 24 hours post. The ability to return to pre-competition IPC force values has been shown to take up to >48hrs (Constantine et al., 2019) but can return above baseline / pre-match results at 72hrs. (Matinlauri et al., 2019). However, in the mentioned Costanine et al., (2019) paper, players abstained from any form of exercise during the 72hrs post-match, something that is not common practice in many football environments, including that of the current study. Nonetheless, the finding that IPC-force produces a similar trend to that of Morgans et al., (2018) who reported an increased CMJ height and peak power three days post-competition in professional footballers is interesting. This suggests that match-play may act an important stimulus for muscle power adaptations. Overall, therefore, while the intensity and density of matches is likely to result in an overall fatigue related reduction in force outputs, there is potential for competition driven positive adaptation depending on when the test may occur.

Importantly, while pre-season strength has been shown to be maintained in the first 12 weeks of the in-season (Rønnestad et al., 2011) the congestion period in this study was 19-30 weeks into the season after the end of pre-season. Additionally, there is evidence in football that stronger players have reduced levels of muscle damage / fatigue 48 hours post-match (Owen et al., 2015). Furthermore, Abbott & Clifford, (2021) demonstrated that stronger academy players recovered quicker after matches. Potentially, the relatively small decrements and increases (seen across the group and individually) in force output seen during the congestion period in this study, could be due to a protective effect of strength gained during the earlier part of the season. Therefore, it should be acknowledged that the adaptations experienced during the previous weeks of the season (combination of S&C, matches, training) may have influenced adaptations to the congestion period. It could therefore be interpreted that the levels of strength obtained during the season, could potentially have a long term positive effect on strength levels even during periods of fixture congestion and reduced strength training frequency. Understanding the consequence of these potential adaptations could be of great significance for the practitioner, especially those who may struggle to create buy-in from players and / or staff for their S&C programme, or feel they have limited time to incorporate practices during fixture dense periods of the season. This further supports the notion that using the in-season phase as purely “maintenance” phase is undervaluing the opportunity to develop athletic qualities that may assist players physical performance, and that taking the opportunity to seek improvements in strength characteristics is worthwhile.

Peak & Mean Isometric force : mid-end season trend

During the mid-end season phase, trivial changes occurred in mean and peak force output in the dominant and non-dominant limb (ES range from 0.002 – 0.06), basically highlighting no change occurred during the 21 days between T11 and T12. These findings contradict previous long-term analysis in other sports, and using different assessment of physical performance (Hene and Bassett,2013), where the trend is for a decrease in sprint performance, aerobic endurance, vertical jump height and 1RM strength in latter periods of a season due to low training, high match loads and increased injury rates.

Results from this study suggest that physical qualities such as isometric force can be maintained, and improved throughout an entire in-season period (T1-12). The overall maintenance of force during the mid-end phase may reflect the diminishing scope for large positive physical adaption during this period. This phase was associated with moderate fixture density compared to previous periods, where 4 matches occurred within the 21 day period (a match on average every 5.2 days, with an S&C session every 10.5 days) but also follows the congested period of high fixture density. This phase was considerably shorter that all previous due to the enforced curtailment of the season as a results of COVID-19 pandemic. We may have seen different trends if the final 6-8 weeks of the season had been played out as planned as originally scheduled. However, the analysis of 88% of the season should still be considered a long enough duration to represent a full season.

Consequently the limited effectiveness of strength training during this period may be associated with the effects of high levels of fatigue which may have built up over the course of the season, as T11 took place at week 35 of the season, after 38 competitive games and numerous training sessions.

Furthermore, it has been shown that injury rates are often greater during periods of the season where accumulated fatigue may be high; such as during congested fixture periods (Bengtsson et al., 2015; Dellal et al., 2013) or towards latter parts of the season (Ekstrand et al., 2011) and despite the maintenance of force output, this phase still contributes to the overall increase see across the season. Therefore, the S&C programme aimed to improve rather than maintain strength may serve as a long-duration protective mechanism against reduction in force and thus injury risk.

Rate of force development

The changes in RFD across the season (T1 – T12) are similar to those observed in changes in force output, with an overall trend for improvements in RFD_{100} and RFD_{200}. In addition, trends for RFD in the specific phases of the season also follow a similar trend. As such, the follow sections on RFD will only discuss key observations that are different to those seen in mean or peak force output.

Rate of force development : overall trend

While the overall trend is similar between force and RFD characteristics, the magnitude of change, however, is less than that seen in changes in peak and mean force. The greater increases in IPC peak force, could demonstrate that an increases in peak force may not necessarily increase the rate at which force can be expressed in professional footballers. The finding that increases in force / strength do not improve power outputs in trained populations is in keeping with previous research (Newton, 1999). This should be considered by practitioners' when planning periodised approaches to maximise RFD in football players. It could also be noted that RFD is largely determined by factors such as motor unit synchronisation and firing frequency (Cormine et al., 2011a). Given that RFD qualities are more sensitive to neuromuscular fatigue than peak force outputs (D'Emanuele et al., 2021, Norris et al., 2019), it is likely that the lower magnitude of change can be associated with the cumulation of overall training load and subsequent fatigue observed over a football season.

Unlike mean and peak force, after the peak in RFD measures at T5 (week 16) the trend is for a general reduction across the season. However, a trend at the end of the season, between T11 and T12 is for a slight increase in output measures. The practical relevance of these findings could suggest that RFD is more sensitive to concurrent training fatigue, and therefore further into a the season, there is a greater chance of a reduction in RFD outputs occurring. Furthermore, the training stimulus may need to be adjusted to allow for improvements throughout the season phases. Enhancements in RFD measured during isometric muscle contractions can be evoked through a range of exercise training modalities, including high-speed movements (e.g. sprinting, jumps, and plyometrics) (Burgees et al., 2007). Whilst exercises training using high-speed movements very likely improve RFD (Kyrolainen et al., 2005), the effects of prolonged heavy strength training on RFD are less clear (Aagaard et al., 2002; Marshall et al., 2011). As this investigation tracks changes in the concurrent practices of football training, that involves high speed movements during football training, and S&C practices that involve high load strength training, it could be little surprise that isometric RFD can be enhanced in professional footballers. However, close tracking and examination of the changes in isometric RFD via multiple time point assessments should occur to see when the rate of improvement becomes minimal, or even diminishes for each player.

As with measures of isometric peak force, as this is the first study which describes changes in RFD output in professional footballers during a full competitive playing season there is no comparative trend data with which our findings can be compared, providing the importance of this current data for further studies to refer to. In fact, very few studies are specifically designed to measure RFD as the primary outcome. In addition, very few studies are conducted in professional sport (Norris et al., 2021; Greco 2013; Graziuli et al., 2019). What is known about RFD and its long-term response to training stimulus, is unequivocal. Studies have shown enhancements (Gruber & Gollhofer, 2004), some change (Tillin et al., 2012), no change (Tillin et al., 2011) or negative trends (Norris et al., 2021) in RFD output at different time epochs. Differences in results can be a results of sport, training stimulus, volume and exercise modality and testing modality (Kubo et al., 200; Gruber & Gollhofer, 2004; Tillin et al., 2011; Norris et al., 2021). In addition, several methodological consideration can alter the reporting of RFD outputs (Maffiuletti 2016) (for further details see page 202).

However, results from a recent meta-analysis (Blazevich et al., 2020) are consistent with resistance training being considered a moderately effective stimulus for early-, late- or max-RFD improvement. Therefore, while we see small to moderate changes in RFD measures across the season, this is likely influenced positively by the inclusion of strength training and aspects of on-pitch training, but negatively by cumulative training related fatigue, which in combines to result in an overall magnitude of change. The positive adaptation of RFD trends are new, novel findings that challenge the notion of RFD decreasing across a season in professional sport (Norris et al., 2021).

Rate of force development: pre-season trend

In this investigation trivial increases in both RFD 100- and 200-ms were observed over the duration of the pre-season. Changes in RFD were greater at 200ms than at 100ms across the pre-season phases in the dominant limb (5.6 vs 2.13% increase) but were greater at 100ms in the non-dominant limb (5.2 vs 3.9%). In addition, RFD 200_{ms} showed a greater magnitude of change as represent by effect sizes, and greater probability of direction change when compared to RFD 100_{ms} (74.1 – 79.4% vs. 56.6 – 63.5%).

While there were increases in RFD during the pre-season, these were only trivial (ES = 0.03 – 0.17). When examining changes in any RFD measures, it is difficult to discern if the observed changes are due to an insufficient training volume or a temporary reduction in performance due to fatigue. During this period RFD_{100} showed the smallest magnitude of change (ES = 0.03; 0.07). Given that RFD is likely to have a neurological basis (Cormie et al., 2011) some degree of neural fatigue may have occurred over the pre-season phase, potentially due to the increase in volume of running experienced during this period. This is further evidenced by the moderate – large increase in RFD_{100} that occurred in the subsequent early in-season phase, despite no notable alteration in S&C training programme volume. Despite still only providing trivial increases, RFD_{200} showed a slightly greater magnitude of change (ES= 0.17 & 0.12). It could be possible, therefore, that the greater period of time to develop force within this measure meant it is less influenced by neural fatigue, as it has been suggested that early (<100ms) is effected greater by exercise induced fatigue than later (>100ms) and peak force (D'Emanuele et al., 2021). A greater improvement in RFD output when there is a longer time to develop force (i.e. RFD_{200}) is perhaps unsurprising when the focus of resistance training during pre-season was on developing strength rather than maximum power or force development (see table 2).

It has previously been highlighted that RFD improvements are greatest within the first few weeks of training, with less ongoing improvements (or even reductions) with longer training blocks even if maximum strength continues to improve (Ogasawara et al., 2013). However, this is contrary to the findings in this current investigation, whereby RFD continues to increase during the subsequent phase of the season, beyond the pre-season phase. This, like with the overall season trend, while we see trivial changes in RFD during the pre-season, is potentially influenced positively but strength training and starting a programme after the off-season break, but larger positive adaptations are potentially blunted by fatigue as a results of the high running volume during this phase.

Rate of force development: early in-season trend

During the early in-season period, moderate increases in early RFD_{100} were observed. However, the greatest change occurred in later RFD production, at 200-ms (ES = 0.72). Heavy strength exercises, rather than ballistic exercises were programmed more consistently across the season and have been shown to affect peak force and later- rather than early force production capabilities (Buckthorpe & Roi 2018; Maffiuletti et al., 2016). It is therefore not surprising that the highest recorded outputs for all measures of RFD occurred during or at the end of this period (T5 or T7), after a sustained period of regular S&C exposure and high intensity (as % of RM) resistance training. Later RFD measures, i.e. 200ms, appears to be affected to a greater extend by this type of S&C training stimulus, training and match load than early (100ms) RFD. This maybe a result of the positive association between RFD and maximal force (Mirkov et al., 2004), especially RFD registered in the later phases (>100ms) of maximal voluntary contractions (Andersen and Aagaard 2006). It has been demonstrated that RFD is influenced by different physiological parameters at early (<100ms) and late (>100ms) phases of isometric contractions. The early phase is influenced by intrinsic muscle properties (Andersen et al., 2010) and neural drive (Gruber et al., 2004), whereas the late phases is influenced by muscle cross-sectional area (Suetta et al., 2004), neural drive (Aagaard et al., 2002) and stiffness of tendon-aponeurosis complex (Bojsen-Moller et al., 2005).

While there is a positive magnitude of effect in RFD 100- and 200-ms in both dominant and non-dominant limbs, the dominant limb produces a greater response than the non-dominant limb. While neural fatigue may impact RFD during the pre-season phase due to the high volume of training load, match related fatigue may have influenced the RFD output during the early in-season phases. This is in contrast to the findings in mean and peak force, where non dominant limb responses were greater during the in-season phase.

The continued rise in RFD_{100} and RFD_{200} in both dominant and non-dominant limbs up to T5 (week 20) contradicts the previously reported suggestion that the majority of RFD improvements occur with the first weeks of training. Does this mean that the concurrent nature of training in professional sport extends the period for improvements in RFD outputs? Or that professional athletes may have a greater ability to produce force quickly even when fatigued?

Rate of force development: congested period

The changes in RFD_{100} and RFD_{200} follow those seen in mean and peak force during the congested period, with decreases in outputs across this period. However, and as seen with mean and peak force, despite showing a drop off in RFD output during the congestion period in relation to the previous phase, both RFD_{100} and RFD_{200} remained above baseline measures (T1) and end of pre-season (T2). Overall, the reduction in RFD output in this period is not surprising, given the greater increase in fixture density (18 matches in 77 days; at a rate of 1 match per 4.2 days). The increase in match play will result in greater levels of fatigue and in turn reduce the ability to produce force rapidly during the subsequent testing of IPC force.

The modern football match requires players to perform a high number of short, high-intensity accelerations (Barnes et al., 2014; Bush et al., 2015) and decelerations (Harper et al., 2019). These actions contribute to high mechanical load and eccentric braking forces, of which the cumulative effect following match play is associated with markers of exercise-induced muscle damage (Russell et al., 2016; Varley et al., 2017). Our results are in agreement with previous research has shown that RFD is particularly affected by muscle damage resulting in a diminished capacity to produce force in both early and later RFD compared to peak force outputs (Jenkins et al., 2014).

Rate of force development: mid-end season trend

After the congested period, RFD began to increase during the mid-end season period, specifically in the dominant limb. During this phase, RFD_{100} and RFD_{200} were still higher than those recorded at baseline (T1) or end of pre-season (T2). This is despite T11 taking place at week 35 of the season, after 38 competitive games and numerous training sessions. While it would be clear that fatigue would play a large role in any force or RFD outcome seen during this phase, we can again demonstrate that physical performance characteristics can be improved throughout the duration of a competitive professional football season. This is in contrast to current research that shows a negative reduction in IMTP RFD in latter phases of the season in elite AFL players (Norris et al., 2021).

Changes in force-time characteristics over the course of the season: sub-group and individual responses

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The response to an exercise intervention is often described in general terms, with the assumption that the group average represents a typical response for most individuals. In reality, however, it is more common for individuals to show a wide range of responses to an intervention. The resultant response often leads to the individual as being classified as high-, low- or negative-responder (Mann et al., 2014). This classification of the magnitude of response following a standardized training intervention may provide helpful insights into mechanisms of training adaptation and methods of training prescription.

Ultimately, individual manipulation of training load is required to optimise an individual's training response and avoid negative outcomes such as injury and overtraining (Halson, 2014). No previous study has examined the individual response of isometric force and RFD, differentiating high- from low- responders, following long term periods of concurrent football and strength training. Therefore, the aim of analysing the individual trends that occur within a group of elite footballers was to highlight the variation that occurs and to provide an understanding of why this is may be the case.

Baseline physical qualities may influence the capacity for adaption over a season (Baker et al., 2006; Norris et al., 2021). Therefore, to help categorise and analyse sub-group response, relative strength levels recorded at baseline testing (T1) were calculated and are outlined in table 10. A simple median split was used to determine those as baseline low or high force producers. The aim was to see if baseline strength levels influenced the adaptions seen across a professional football season.

Analysis of response over the season (T1-T12) was determined in two ways. The first, like baseline strength, was a simple median split to categorise athletes as low or high IPC relative force producers dichotomised according to baseline (T1). An athlete with a negative % change was automatically categorised as a negative responder. The results of using the median split will be presented in the following sections: Peak & Mean Isometric force : overall trend and Rate of Force Development : overall trend.

The additional analysis of individual change that can be used is smallest worthwhile change (SWC). SWC allows practitioners' to see if a change in test performance is actually practically worthwhile to that individual. The interpretation of SWC can produce 4 thresholds: small, moderate, large and very large change, and has been proposed for use in professional sport to determine individual response (Buchheit, 2016). Any athlete with a change less than the SWC was termed a negative or non-responder. The results of using the SWC will be presented later, in the "Response to in season training load: methodological issues" section.

Peak & Mean Isometric force : overall trend

The present study compared isometric performance within a squad of footballers, with the group dichotomised to low (*n*= 9) or high (*n*= 9) strength based on a medium split of baseline (T1) relative force output. Based off the median split, low baseline force players showed overall greater magnitude of improvement in mean (14.7%) and peak (9.6%) force than HB-force players (5.4% and 4.4%) across the season. More specifically, the player with the lowest baseline force output (A14), showed a 35.3% increase (the highest in the group) in mean force and a 23.1% increase (2nd highest) in peak force from T1-12. In comparison, the athlete with the highest baseline force output, A10 showed a minimal increase in mean (4.7%) and peak (4.0%) force output across the season. Moreover, the 3 largest individual percentage changes across the season occurred in the 3 lowest force producing players at baseline testing (A14, 8 and 6) (see table 11). Interestingly, player 5, who was categorised as the 2nd strongest at baseline testing for mean and peak force, experienced the lowest change in mean (-3.9%) and peak (-7%) IPC force across the season.

One of the reasons why individual responses are not frequently reported in the literature might be due to the lack of clarity in classifications. It has previously been suggested that individuals that encounter adverse effects or those in which training outcomes decline or show little to no improvement are deemed low responders (Dankel & Loenneke, 2020). Additionally, the nature of categorising individuals as responders or non-responders may lead to misclassifications, particularly based on a specific outcome. In the example of athlete 5 who expressed an negative change in mean and peak force, he actually expressed a 17% increase in RFD_{100} across the season. Thus it is important to remember that where an individual may not respond to a given programme or variable, it does not instantly qualify them as a non-responder to the exercise stimulus.

As suggested, the ability to categorise those as high-, low- or non- responders is difficult. In fact, it is not often reported how subjects are grouped into high-, low- or non-responders when expressing individual variation in athlete response (Rantila et al., 2021). As such, in this investigation we used a simple median split of seasonal % change to categorise low or high responders. Athletes with an minus % change were automatically determined to be a negative or non-responder. The median split revealed that a greater number of low-baseline force players had a high response across the season, and as such were categorised as high-responders in mean (5 low vs 3 HB-force players) and in peak (6 low vs 3 HB-force players) force. These results show than when accounting for baseline relative lower body strength, elite football players with LB-strength show a greater capacity for seasonal improvements. These findings are in agreement with those seen in elite AFL players (Norris et al., 2021) but are reported for the first time in elite football players. In contrast, athletes with higher baseline force showed a greater capacity for a low-response across the season. There was no difference in number of players who reported a negative change in force based on baseline force. Our results indicate that there is not a one-size fits all approach to strength training in a group environment. The results agree with previous literature that reports differential adaptations between weak and strong athletes, whereby improvements in strength maybe easier to come by in those weaker athletes (Cormie et al., 2010; Norris et al., 2021). As well as response varying between differing levels of strength, it has been proposed that different training stimuli could evoke similar chronic training responses between individuals (Cormie et al., 2010). In other words, an athletes' individual physical qualities may benefit from a specific stimulus at a given time point (Cormie et al., 2010). Cormie et al., (2010) show that once a level of strength has been achieved, stronger athletes need a power stimulus to improve rapid force production capabilities, whereas weaker athletes can improve power output from strength training alone. In further support of these findings, Jones et al., (2020) assessed the change in strength within academy aged (U11-18) football players across a 42 week season. Results showed that stronger players at pre-season experienced strength loses, while those who were weaker gained strength across the season. It was concluded that stronger academy aged footballers were exposed to insufficient training stimulus to maintain or drive further strength gains, and that when players presented with high pre-season strength, individualised programmes should be considered.

Besides the requirement for different training stimuli, it has been suggested that athletes with relatively higher testing scores will find it harder to attain a given change when compared to those with relatively low scores (Datson et al., 2021). In other words, stronger athletes may already be at, or very near their athletic potential, and their ceiling for further positive adaptation maybe limited. In contrast, those weaker athletes have a larger window of opportunity to change as they are not close to reaching their physical potential.

It is evident that the observations in force and RFD outputs across the season is not the same in all players. The individual change in force and RFD show large variations between participants. For example, the individual change in mean force seen across the season ranges from -3.9% decrease, to a 35.3% increase. Additionally, the individual change in RFD_{200} seen across the season ranges from a -29% decrease, to a 63.9% increase. This would suggest that some players improve their isometric force production while others actually decrease from their baseline isometric force over the course of a competitive season. The exact reasons for these individual disparities are difficult to accurately report in this investigation as there are many potential factors.

One potential factor may be the varying exposure of individuals to the strength training sessions. All efforts were made for players to attend and complete sessions, but as is the real world nature of this study, player compliance to the sessions may be compromised by fixtures, injuries, media duties, player appearances or other personal issues that arise during the season. Another potential factor for the varying individual response may be explained by insufficient recovery during 9 months of high training and competition volumes associated with first team football. Such a prolonged period of frequent training and competition may cause fatigue to accumulate and likely result in suboptimal neuromuscular performance over a season (Caldwell & Peters, 2009).

Overall, the trends seen across the season may suggest the need for the practitioner to optimise training programme compliance and developing individual approaches to the prescription, monitoring and assessment of resistance training programmes in elite football players.

Peak & Mean Isometric force: pre-season trend

When viewing the response of the group during pre-season, there is a trivial increase in force output and a small decrease in non-dominant limb peak force. What is interesting is that when viewing the sub-group responses, increases in both mean and peak force are observed in the low baseline force group, with decreases being evident in mean and peak force for the HB-force group (see figure 6 a and b).

Peak & Mean Isometric force: early in-season trend

During the early in-season phase, there appears a different level of response between the LBF and HBF, in both mean and peak force measures.

In the LBF group, mean force fluctuates throughout the phase, with two separate peaks at T3 and T5 (highest of season) before a reduction during the remainder of this phase. In comparison, for peak force, there is an increase from baseline to T3, then a decrease in output until rise again between T6-T7. In contrast, in the HBF group, mean and peak force increase from end of pre-season (T2) to the first test of the in-season, (T3). After that initial increase, there appears a predominately stable force output throughout this phase. These results could suggest that the training frequency, volume, content is driving positive changes in LBF group, but that although force is maintained in HBF group, these athletes may need a change in stimulus to create further improvements. This could be an increase or decrease in volume, or intensity, or a change of exercise focus.

Peak & Mean Isometric force: congested period trend

The group response showed that while the overall trend during this period was for a reduction in mean and peak force during this period, surprisingly the highest mean and peak force outputs for the season were recorded during this period.

An interesting finding during this period was that during the congested period, the HB-force group showed a trend towards increases in peak force output (see figures 6 a and b). In comparison, the low baseline force group showed a trend towards a slight decrease during the same phase. It could therefore be proposed that those who are “stronger” at baseline are able to tolerate the demands of fixture congested related fatigue better. This finding is supported by research in elite Australian Football League players, where higher lower body strength and power may improve match load related responses in neuromuscular function (Norris et al., 2021). Furthermore, previous research, has shown that stronger Rugby league players showed similar neuromuscular function recovery post-match, despite performing higher amounts of external load (total distance and HSR) (Johnston et al., 2015). While it is not possible to directly infer these findings, it may suggest that players with above-average levels of strength may find exposure to high intensity actions less physically taxing. This could be of interest to the S&C practitioner as it may provide evidence to support the concept that being stronger helps recovery from match play that has been previously reported in football (Owen et al., 2015) and AFL (Norris et al., 2021) and therefore potentially help athletic performance. It also supports the justification for viewing and reporting individual changes during this period, as you would miss some of the positive adaptations if you were to view the group response in isolation.

Peak & Mean Isometric force: mid to end season trend

During this phase, both groups show a slight decrease in peak force isometric performance at the start of this phase (T10-T11). However, both groups show a trend to improve across this phase. The biggest change in trend during this phase occurs for mean force between T10 and T11 in the LBF group. In fact the response at T11 is the lowest within the season apart from baseline or end of the pre-season. Nevertheless, as with overall group response in this phase, LBF and HBF groups are producing more force than at baseline (T1) or end of pre-season (T2). Therefore, it appears that athletes who have a higher baseline force capacity, may be able to cope with the demands of the season, and in particular the fatigue related effect of the congested period, to a greater extend that LBF athletes.

Rate of force development

The changes in RFD seen within the sub-groups and individuals are similar to those observed in changes in force output, with an overall trend for improvements in RFD_{100} and RFD_{200} for the low and high force groups across the season. As such, the follow sections on sub-group and individual RFD will only discuss key observations that are different to those seen in mean or peak force output.

Rate of force development : overall trend

While RFD response across the season with the group, sub-group and individual level show a similar trend of improvement across the season, RFD responses show greater variance at an individual level (figure 5).

A median split of athlete responses revealed that a greater number of LB- force players had a high response across the season, and as such categorised as high-responders in RFD_{200} (5 low vs 1 HB-force players). These results show than when accounting for baseline relative lower body RFD, elite football players with LB-RFD show a greater capacity for seasonal improvements. In contrast, athletes with higher baseline RFD_{200} showed a greater capacity for a low-response across the season. These trends are similar to those seen in mean and peak force, which may not be surprising given the link between peak force and late RFD (Andersen and Aagaard 2006). Furthermore, it expands on the understanding that athletes with lower strength and power may have a greater window of opportunity for physical development within a football season with the inclusion of strength training protocols. However, it also suggests that stronger athletes may need careful periodisation and individual consideration of their programme to help improve their responses across a season. There was no difference in number of players who reported a negative change in RFD_{200} based on baseline force. However, there were more players who had a negative or non- response in RFD_{200} performance than with any other measure of force characteristics. In total, 7 of the 18 players had a negative response.

Rate of force development : pre-season trend

During the pre-season phase, improvements could be viewed in both low and HB-force groups for RFD_{100} and RFD_{200}. However, the trend appears for improvement appears to be greater in the LB-RFD athletes. The progressive increase in RFD_{100} and RFD_{200} continues until T5 during the in-season for LB-RFD athletes.

Rate of force development : in-season trend

While there is a progressive increase in RFD for LB-RFD athletes from pre-season through the in-season, HB-RFD athletes show a drop off in RFD_{100} and RFD_{200} from the end of pre-season (T2) through the first part of the in-season (T3). However, from here measures of RFD increase until a season peak at T5, before a second drop until the start of the next phase (T7). In contrast, the LB-RFD group demonstrate a reduction in output at T6 before reaching a season peak at T7.

Rate of force development : congested phase trend

An interesting observation seen at the start of the congested phase is that the LB-RFD group demonstrate an immediate, substantial drop off in RFD_{100} and RFD_{200}. In contrast the decrease in RFD output seen across this phase in all other group and sub-group measures, occurs later into this phase in the HB-RFD group. Although only speculative, it may suggest that although a reduction in RFD is inevitable during this phase as a result of acute and accumulative fatigue as a consequence of the high density of match play, athletes who produce higher RFD output at baseline testing may delay the negative effects of this fatigue on their isometric strength.

Despite the decreases in both LB-RFD and HB-RFD outputs, both groups still produce higher RFD outputs than reported at the start (T1) and end of pre-season (T2) phase. Like with the other force characteristics measured, it may demonstrate that the improvements made during the previous phases can result in a protective effect during the congested period.

Rate of force development : mid-end trend

During this phase, both groups show a slight decrease in isometric performance at the start of this phase (T10-T11). However, both groups show a trend to improve across this phase, with a greater increase visible in the HB-RFD group. Therefore, as with the trends seen with mean and peak force measures, athletes who have a higher baseline RFD capacity, may be able to cope with the demands of the season, and in particular the fatigue related effect of the congested period, to a greater extend that LB-RFD athletes.

Response to in season training load: methodological issues

As previously discussed, , the ability to categorise individuals as high-, low- or non-responders is difficult. In fact, it is not often reported how subjects are grouped into high-, low- or non-responders when expressing individual variation in athlete response (Rantila et al., 2021). In this section, some of the methodological issues associated with reporting these responses will be discussed.

The results largely discussed in the previous sections are based on the median split of athletes response. An alternative method to determine magnitude of change is using SWC (Hopkins et al., 2009). SWC is a reference value selected by a practitioner or researcher to indicate a value beyond which a change in true score is likely to be meaningful in practice. Fundamentally, what actually matters to practitioners' is whether the training-related changes could be important, i.e. whether their magnitude of change is actually greater than the smallest practical or meaningful effect for a given task (Batterham and Hopkins, 2006; Hopkins et al., 2009). Recently, Buchheit (2016) proposed that thresholds for SWC in athletes similar to those seen with Cohen's d (Cohen 1988). It was suggested that any change of 1x SWC would be considered small, 3x as moderate, 6x as large, and 10x as very large. If these principle thresholds were applied to the findings in this study we could determine that for mean force, 4 players would be considered to have non-or negative responses; 6 players considered to have a small response; 3 players considered to have a moderate response; 2 with a large response; and 3 players would be considered to have a very large response to within-season training load. Interesting, 4 out of the 5 players considered to have a large or very large response are athletes with LB-force (A4, 6, 8, 14, 16). The trend is similar for peak force, where 3 of the 4 players reporting large and very large responses were athletes in the LB-force group (A6, 8, 14, 16).

Therefore, the findings are in agreement with results from the median split, which suggests that players with LB-force may have a greater opportunity for across season improvements in force-characteristics.

Limitations of the study

While this research offers new and interesting findings regarding changes in force output in professional football players across a season, it does not exist without limitations.

Due to the uncontrolled nature of the present study, it can only be descriptive and thus report trends in isometric force and RFD over the course of a season. Unfortunately, this design does not allow us to say exactly what caused the responses in the players. Certainty, it could be due to the inclusion of strength and conditioning practices, but it could also be due to other factors such as training load, match involvement, personal motivation, sleep, or nutrition. The research is limited by the lack of detailed information provided regarding volume and intensity of all types of training undertaken over the season such as training or match load. Therefore, caution should be exercised when interpreting the reduction in lower limb isometric strength observed in certain individuals in the report, as each players training and match selection process is unique and potentially different to those who responded more positively. This limits the accuracy of inferences that can be made regarding the basis for change in physiological characteristics as these are likely to differ within the 18 players analysed in this research.

Another limitation would be that this research was conducted on one team. Reporting data from multiple teams would help increase the validity of the findings and its application to a wider demographic. This therefore has an impact on the ability to generalise from this data and to make assumptions around the suitability of the same outcome for others. However, as every team is likely to experience different, unique training environments, training loads and frequency of S&C sessions it would be difficult to standardise the methodology for a larger sample of teams. The results seen in this study may only be applicable to this team, but still provide new information regarding the change in trend of isometric force and RFD in professional footballers. Despite these limitations, the data is novel and we do believe that researchers and practitioners' may benefit from a set of data based on elite football players. These types of designs are clearly important in such applied settings as they represent one of the only strategies that can be used to answer research questions in the “real world” environment of professional football.

Future research direction

A focus of this current research was to understand the individual responses within a playing squad across a season. A key benefit of monitoring neuromuscular performance in elite sport settings is gaining insight into the individual response to a given training and/or competition stimulus, which could inform management of acute recovery strategies or long-term athletic development plans. Further quantification of total work performed by players in both match and training may provide greater insights into the factors which affect change in force and RFD qualities over the course of a season. The widespread use of GPS data within professional football represents a means of quantifying both distances covered and the frequency of high intensity efforts. Relationships between measures of external load performed in matches (e.g. number of accelerations, volume of high-speed running) versus subsequent neuromuscular performance across a season could be of interest to the S&C practitioner to help gain a more complete understanding of individual athlete response. Whilst this study provides a descriptive overview of force output characteristics responses to concurrent training, a greater understanding regarding the influence of match frequency or involvement would enable the strength and conditioning coaches to optimise the resistance training prescription to players further.

Practitioner experience suggests that time available for suitable resistance training is the number one barrier to the inclusion of S&C training in professional football (Project 1). The inclusion of resistance training in the football environment is still challenging, and is often still confronted with historical view point that “weight training will get the players too big”, or the short term negative effects of strength training (such as stiffness or muscle soreness) on recovery or preparation for matches. In such circumstances such as the congested fixture phase, where strength training has to fit into a small window of opportunity during a training week, it becomes almost impossible for many players to perform any lower limb strength training. It may be of use to S&C practitioners' for research to highlight methods of including resistance training stimuli during these periods to help maintain performance and reduce risk of injury. A more detailed analysis of the type of strength periodization followed across a season would help to assist the practitioner in optimizing their approach.

Future studies many look to extrapolate this research design to include other teams in the same league so that sample size can increase, and comparisons of S&C frequency can help practitioners' understand the best possible programme to use during a competitive football season.

Finally, how standardised changes / differences are presented is crucial for a better understanding of magnitudes. Therefore, it may be of use for the researcher to attempt to report how thresholds of high- low- and non-responders are determined for individual change to allow this interpretation to become more readily available to practitioners'.

Practical Application

Coaches should be interested in the findings that force production and RFD can be improved within the group and on an individual basis across a competitive football season. Results of a study like this are not designed to find the direct causation of the changes seen, merely to highlight the trends that occurred. However, the S&C programme that was designed during this season was aimed to improve strength and physical capacity, not to merely maintain strength gains produced in pre-season. With the relatively small changes in isometric force characteristics seen during the pre-season, and the ability to have continued larger increases during the in-season, there could be a suggestion that the early phases of a season should be considered as an extension of the pre-season, whereby strength training protocols should look to develop improvements in strength, not merely be expecting maintenance or early reductions in performance.

This study confirms the importance of regular monitoring in elite football players during in season phases. A lot of the original and interesting findings reported in this study would not have been possible without frequent monitoring assessment. Most research monitors change are often limited to pre- and post-intervention, or at certain set times e.g. every 6 weeks. The novelty in this study was that 12 testing dates were included and therefore trends could be viewed at specific phases during the season. This allowed greater detail and understanding of group and individual response that may have been hidden if assessment only took place less frequently throughout the season. Therefore, it would be advised that practitioners' aim to assess their players as frequently as possible over the course of the season.

Although group analysis shows moderate isometric force changes over the duration of the season, individual players can experience varied responses. We have shown for the first time in professional footballers that there can be athletes within the group setting that have high, low- or negative responses to concurrent match play and S&C practices across the season. This may be due in part to adequate or suboptimal training stimuli; fatigue responses as a result of training and match play or, most likely a combination of a number of factors. The S&C practitioner should therefore be interested in these low- and negative responders, as for some, the intervention needs to be altered to aim to improve their response. This could be an adaption (increase or decrease in volume, frequency or intensity) of: strength or power training; recovery; and/ or training load. Therefore, strength and conditioning professionals working in elite football are encouraged to adopt individual strength monitoring instead of only tracking squad changes, and to use the resultant data to individualise part of the players strength training programme.

Importantly, this investigation has highlighted that considering baseline isometric force may be required when assessing seasonal direction and magnitude of adaptation on mean or peak force and RFD. This may have important practical applications for S&C practitioners', allowing for a more accurate description of training response, and identifying accurate and appropriate training and recovery protocols. In particular, higher levels of lower limb isometric force may facilitate improved tolerance of higher doses of external work, which may expedite neuromuscular recovery, and positive physical adaptation. Our results show that while those who have LB-strength showed greater seasonal improvements, those who are stronger at baseline testing are less likely to have a reduction in their force output during the congested periods of a season. For a practitioner, it would useful to improve an athletes strength as early in the season as possible, as it may facilitate improved tolerance of higher workloads, and which in turn may assist the rate of recovery and mitigate the risk of injury.

Choosing the type of assessment method is also crucial in team settings. The IPC test used in this research has been shown to be a reliable testing procedure to assess changes in force production. In addition, utilizing the IPC test compared to more popular used assessments such as the Nordic Hamstring Exercise, allows for quick, easy to administer, and non-impactful assessment of an athletes physical capabilities, and as such lends its hand to being used frequently in a season, even during the periods of fixture congestion. It could be advised for practitioners' to utilise assessments, like the IPC that provide information about an athletes physical status, without putting any additional risk or load into the players.

Finally, where possible assessment of RFD may provide useful, additional information to understand player response. RFD characteristics collected from the IPC test may give additional information into a players current neuromuscular status that is not achieved by measures from peak or mean force alone. In particular, early RFD (RFD_{100}) may give an insight into potential neural underpinnings of fatigue that may be missed by other measures. However, careful consideration of the methodology used to assess RFD is required, as many factors can determine the accuracy of the results.

Conclusion

The purpose of training during a football season should be on improving components of physical fitness. It is often reported that in-season phases should be focussed on maintenance or that only maintenance or reduction of strength is possible. The findings from this investigation have shown for the first time, that on a group level, isometric force and RFD output can be improved during a full season. Additionally, players are likely to experience individual variations in physiological response to load across a season. Individual analysis conducted in this study showed that across the season, and during different phases of the season, players experience varied responses in force production. Such individual differences are potentially dependent on base line strength levels, and changes in force production across a season are likely to be influenced by a number of factors such as match play, the resultant accumulation of fatigue, and response to a resistance training stimulus.

Although it is conventional to focus on the group mean response following a particular training intervention, individual responses typically show considerable variation, including particularly ‘high responders’ and particularly ‘low responders’ or ‘non-responders’ for a certain training response parameter. A high responder measured in one variable of a monitoring assessment (e.g., change in RFD_{100ms}) may not necessarily be a high responder in another variable (e.g., mean isometric force), implying that the same individual could potentially be described as both a ‘responder’ or a ‘non-responder,’ depending on the outcome variable of interest. It is therefore important to monitor and understand the value in a number of different variables to develop a complete understand of the athletes adaptation and needs.

Finally, this investigation has also shown that tracking isometric force output measures using IPC test during in-season phases of competitive football provides insights for practitioners’ that may help make informed decisions to optimise training load at an individual level.

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Supplementary information

Project 2

Comparison of injury rates across two pre-season phases in one professional football team

Protocols for testing

Counter-movement jump (CMJ)

Players were instructed to stand with hands-on-hips and feet shoulder-width apart (Petrigna et al., 2019). Players could self-select the depth of the counter-movement prior to jump-take off (Cormack 2008). Players were instructed to move as quickly as possible during the counter-movement and take off with maximal intent. Hands were maintained on the hips for the duration of the movement. During the apex of the jump, participants were expected to keep their legs fully extended, before landing with both feet back in a shoulder-width stance. Each player performed 3 jumps, with 30 second rest between each attempt. The maximum height from the 3 trials was recorded for analysis.

Squat Jump (SqJ)

Players were instructed to stand with hands-on-hips and feet shoulder-width apart (Petrigna et al., 2019). Players were instructed to squat down to a position roughly 90 degree knee flexion. Players had to hold this position for 2 seconds before being instructed to jump and take off with maximal intent. Hands were maintained on the hips for the duration of the movement. During the apex of the jump, participants were expected to keep their legs fully extended, before landing with both feet back in a shoulder-width stance. Each player performed 3 jumps, with 30 second rest between each attempt. The maximum height from the 3 trials was recorded for analysis.

Single leg counter-movement jump (SL CMJ)

Players were instructed to stand with hands-on-hips on one leg. Players could self-select the depth of the counter-movement prior to jump-take off (Cormack 2008). Players were instructed to move as quickly as possible during the counter-movement and take off with maximal intent. Hands were maintained on the hips for the duration of the movement. During the apex of the jump, participants were expected to keep their legs fully extended, before landing back on the one, take-off leg. Each player performed 3 jumps, with 30 second rest between each attempt. The maximum height from the 3 trials was recorded for analysis before the test was then repeated on the opposite leg. Limb dominance was defined as the players dominant / preferred kicking limb.

Single leg box squat (SLBS)

Players were instructed to stand on one leg, on a box. The box measuring 30 cm high was used for all participants. An additional heel raise was used for players who had ankle range of motion problem. Participants were instructed to use their hands to lightly balance if required against the wall. Standing on one leg, participants were instructed to squat down until the heel of the non-working leg touched the floor. Players were advised that the aim of the test was to do as many repetitions as possible until failure. The tempo per rep was set at a 1 second up, 1 second down. When the correct form was lost, one warning was given and the test was ceased at the next fault in technique. Repetition maximum was recorded and the test was then repeated on the opposite leg after a short rest.

Single leg calf raise (SLCR)

Players were instructed to stand on a box facing a wall. The box measuring 30 cm high was used for all participants. Participants were instructed to use their hands to lightly balance if required against the wall. Standing on one leg, participants were instructed to lower their foot / ankle below the level of the box, and then perform a calf raise, until full ankle plantarflexion and knee extension was achieved. Players were advised that the aim of the test was to do as many repetitions as possible until failure. The non-working leg was required to be held stationary in a vertical position to ensure that momentum was not gained by swinging this leg. The tempo per rep was set at a 1 second up, 1 second down. When the correct form was lost, one warning was given and the test was ceased at the next fault in technique. Repetition maximum was recorded and the test was then repeated on the opposite leg after a short rest.

Single leg hamstring bridge (SLHB)

The SLHB test is a clinical test for hamstring function used in screening programmes at the elite level and shows a relationship between strength and injury risk (Freckleton et al, 2013). Players were instructed to lie down on the ground with one heel on a box. The box measuring 30 cm high was used for all participants. The test leg was positioned in approximately 90 knee flexion. Participants were instructed to cross arms over the chest and push down through the heel to lift their bottom off the ground. Players were advised that the aim of the test was to do as many repetitions as possible until failure. Each trial included the participants touching their bottom onto the ground, without resting, and then extending the hip to 0 degrees. The non-working leg was required to be held stationary in a vertical position to ensure that momentum was not gained by swinging this leg. The tempo per rep was set at a 1 second up, 1 second down. When the correct form was lost, one warning was given and the test was ceased at the next fault in technique. Repetition maximum was recorded and the test was then repeated on the opposite leg after a short rest.

Body Composition

To estimate body composition / adiposity, skinfold thickness was measured across 7 sites on the right side of the body; Chest (pectoral); Abdomen; Thigh (quadriceps); Triceps; Subscapular; Hip (suprailiac or iliac crest); Midaxillary (armpit at fifth rib), using a Harpenden skin-fold calliper (British Indicators Ltd., Luton, England) for calculation of percent body fat according to equations described by Jackson-Pollock.

Table 1. OSIICS, Orchard sports injury and illness classification system for injury location

Main grouping	Category	Equivalent OSIICS body area character
Head and neck	Head / face	H
	Neck / cervical spine	N
Upper Limbs	Shoulder / clavicula	S
	Upper arm	U
	Elbow	E
	Forearm	R
	Wrist	W
	Hand / finger / thumb	P
Trunk	Sternum / ribs / upper back	C ,D
	Abdomen	O
	Lower back / pelvis / sacrum	B, L
Lower limbs	Hip / groin	G
	Thigh	T
	Knee	K
	Lower leg / Achilles tendon	Q, A
	Ankle	A
	Foot / toe	F

Table 2 . OSIICS, Orchard sports injury and illness classification system for injury type

Main grouping	Category	Equivalent OSIICS pathology character
Fractures and bone stress	Fracture	F
	Other bone injuries	G, Q, S
Joint (non-bone) and ligament	Dislocation / subluxation	D, U
	Spain / ligament injury	J, L
	Lesion of meniscus or cartilage	C
Muscle and tendon	Muscle rupture / tear / strain	M, Y
	Tendon injury/ rupture / tendinosis	T, R
Contusions	Haematoma / contusion/ bruise	H
Laceration and skin lesion	Abrasion	K
	Laceration	K
Central / peripheral nervous system	Concussion	N
	Nerve injury	N
Other	Other injuries	G

Project three

Annual Plan																																									
Month	June - July					August					September				October					November				December					January				February					March		April	May
Week No.	wk 1- 5					wk 6-10					wk 11-14				wk 15-19					wk 20 -23				wk 24-28					wk 29 - 32				wk 33 - 37					wk 38 - 42			
Microcycle	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39		
Phase	Pre Season					Competitive In- Season																																			
Monday		S	S			T2	S			S			S	T4	S							S																			
Tuesday			M	S	S	S		S		M				S				M		T6		S	M	T7 S	M	T8 S			T10 S		S	M	M		T11 S	M	S	T12			
Wednesday	T1	S							M		T3				M					S								M		M				M				S			
Thursday	S			M							S					S											M													Season Postponed Covid-19	
Friday		M										M					M										T9					M									
Saturday			M	M	M	M	M	M	M	M			M	M	M	T5			M		S	M	M	M	M	M		M	M	M	M		M	M	M	M	M				
Sunday																S		M		M							M											M			

Match	M	49
Testing	T	12
S&C	S	26

week 10	S&C	non starters next match

Figure 1. Schematic representation of the annual plan including matches, S&C sessions and IPC testing dates