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A stress-based examination of the impact of injury occurrence in elite youth football players

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Candidate declaration

This is to certify that, except where specific reference is made, the work described in this thesis is the result of my own research. Neither this thesis, nor any part of it, has been presented, or is currently submitted, in candidature for any other award at this or any other University.

Signed *James Robert John Silver*
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Abstract

This thesis examined the impact of non-contact injury on the physical and psychological development of elite youth academy footballers (14.1 to 23.0 years old) and considered which physical and psychological measures might indicate risk of non-contact injury. Three studies, based on longitudinal observational designs, surveyed players during a critical stage in their football careers across separate seasons, comprising of a pre-season and competitive season. Most observed players were within the under 18 age group since this age range has been associated with high frequency and severity of injury. Study 1 assessed the impact of hamstring strain injuries (HSI) due to the known prevalence in elite football. Players not sustaining a HSI exhibited increased eccentric hamstring strength (mean difference (MD), 47 N 95%, confidence interval (CI) = 3 to 91 N; probability value (*p*) = 0.0378) and body mass (MD, 1.7 kg 95% CI, 0.1 to 3.3 kg; *p* = 0.0427) and were 2 years younger (MD, -2.1 years; 95% CI, -3.6 to 0.7 years; *p* = 0.0053) compared to those sustaining a HSI. Study 2 examined the impact of reduced training and match availability. Low availability alleviated pitch-based exposure, as players with high availability had superior accumulation of training and match stimuli (e.g., total PlayerLoad^{TM}: MD, 12726 au; 95% CI, 4211 to 21242 au; *p* = 0.0053). Contrasting with low availability, high availability players had significantly lower sit and reach scores (MD, -9.8 cm; 95% CI, -16.9 to -2.8 cm; *p* = 0.0091) and counter movement jump (CMJ) peak landing force asymmetry (MD, -14.86%; 95% CI, -29.14 to 0.57%; *p* = 0.0422) at pre-season. This suggested potential hypermobile characteristics and less neuromuscular control when landing could influence availability for the upcoming season. Study 3 also assessed the impact of reduced training and match availability and incorporated additional psychological measures. Compared to high availability, players with low availability had greater development in CMJ eccentric mean force (*p* = 0.0307), and greater increases in CMJ take-off peak force asymmetry (*p* = 0.0237). Reduced playing availability impacted psychological development. Players categorised with moderate availability, had reduced coping resources (e.g., active coping: *p* = 0.0043) compared to those with high availability. Players with low availability across the competitive season had higher fluctuations of stress and recovery compared to players with high availability (*p* = 0.0046). Across all three studies relationships were observed independent of non-contact injury. Numerous relationships were identified between measures of physical fitness. For instance, greater CMJ development suggested possible improved change of direction times (e.g., jump height: *p* = 0.0013). Multiple relationships were found between growth and physical fitness development and exposure variables. For example, training total PlayerLoad was associated with CMJ jump height (r = 0.62, large; *p* = 0.0043). Furthermore, multiple relationships were demonstrated between physical and psychological development. These findings denote how assessment techniques can be utilised to facilitate monitoring players for injury risk and/or their physical and psychological development, whether they are available to train and compete, or are rehabilitating.

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List of Abbreviations

Add	adductor
au/AU	arbitrary units (measurement of workload based on the Borg Rating of Perceived Exertion Scale). For reference: low, ≤ 4 au; moderate, > 4 au and < 7 au; and high > 7 au) as proposed by Lovell, El Ansari and Parker, (2010). Workload can be calculated by multiplying perceived exertion, e.g., (5) by session duration (60 mins) to give a workload of 300 au.
AFL	Australian Football League
ALES	Athletic Life Experience Survey
ASRM	athlete self-report measures
asym	asymmetry
BAS	Behavioural Approach System
BF	Biceps femoris
BFLH	Biceps femoris long head
BFSH	Short head of the biceps femoris
BIS	Behavioural Inhibition System
CB	Centre back
CI	confidence interval
CL	confidence limits
conc	concentric
cm	centimetre
CM	Centre midfield
CMJ	Counter movement jump

CS	competitive season
CV	coefficient of variation
Df	dorsiflexion
DJ	Drop jump
DROM	Dynamic Range of movement
ecc	eccentric
EL	External Load
EPPP	Elite Player Performance Plan
FB	Fullback
FFFS	Flight-Fight-Freeze System
FMS	Functional Movement Screen
GK	Goalkeeper
GPS	Global positioning systems
H	Hours
HSI	Hamstring strain injuries
HSR	High speed running
Hz	Hertz
ICC	intraclass correlation
IL	Internal Load
IMA	Inertial movement analysis
Kg, kg	kilogramme
LESCA	The Life Event Survey for Collegiate Athletes
L and R	Left and Right
m	metre
M	mean

max	maximum
Md	Match day
Mf	mean force
ML	Match Load
MD	mean difference
MDC	minimal detectable change
mins	minutes
mm	millimetre
mmHG	millimetres mercury
ms	milliseconds
n	number (e.g., of participants)
N	newton
n/a	not applicable
NF	Nordic force (measured in newtons)
NHE	Nordic hamstring exercise
p	probability
pf	peak force
PHV	Peak height velocity
POMS	The Profile of Mood States
PMA	Performance Management Application
PS	pre-season
r	correlation coefficient
reps	repetitions
RESTQ	The Recovery-Stress Questionnaire
RESTQ-Sport-52	The Recovery-Stress Questionnaire for Sport (52 items)

RDM	Reliability difference of the mean
RFD	Rate of force development
RHR	Resting heart rate
ROM	Range of movement
RPE	Rate of perceived exertion
RR	relative risk
RST	Reinforcement Sensitivity Theory
rRST	Revised Reinforcement Sensitivity Theory
RST-PQ	The Reinforcement Sensitivity Theory Personality Questionnaire
s	seconds
SD	standard deviation
SEM	standard error of the mean
sf	sample frequency
SL	satellite lock
sphy	Sphygmomanometer
SSC	stretch shortening cycle
ST	Striker
TD	Total distance
TE	typical error
TL	training load
U	Under (as in Under 18 age group)
v	Version (referring to software)
WG	Winger
yrs	years

Chapter 1: Introduction

1.0 Introduction

Academy football shapes the initial stage of a footballer's career and is critical for their long-term development and progression to an elite senior first team (Le Gall *et al.*, 2010). The importance of academy footballers achieving elite senior level is reflected in the frameworks and large-scale investments of both professional clubs and governing bodies into academy systems in England and Wales, and also the personal sacrifices and investments of the youth players and their families. This multi-faceted endeavour requires extensive research to inform optimal processes for academy footballers, their clubs and families, and governing bodies (Mills *et al.*, 2014; Saward *et al.*, 2020; Read *et al.*, 2018b; Noon *et al.*, 2015). Developing youth footballers into elite senior players has a high failure rate within the English and Welsh academies, less than 1% of academy players within the UK are offered a professional contract and only 0.012% (180 of 1.5 million) of footballers within English academies play in the senior Premier League (Mitchell *et al.*, 2014; BT Sport Films, 2018). Between the 2009/10 and 2017/18 seasons academy players growing up in England and Wales were on average exposed to less than half a match within Premier League senior fixtures (Poli, Ravenel and Besson, 2019). These observations beg the question why, and what, is preventing more youth players with Premier League academy systems from progressing to senior standards.

Academy players must be available to train and compete to develop physically and technically to an elite senior standard. Time lost due to injury can have a detrimental impact on development because these opportunities are missed (Ward *et al.,* 2007). Additionally, once injured the football player is more susceptible to future injuries and maladaptation detraining effects because of being unable to train (Price *et al.*, 2004;

Rodríguez-Fernández *et al.*, 2018). Ultimately, sustaining an injury and losing critical playing time could be the deciding factor which determines whether, or not, an academy footballer can progress their career and secure a professional contract (Le Gall, Carling and Reilly, 2009). Since so few academy players progress to an elite senior level, it is crucially important to mitigate any injury risks to ensure that they develop to their maximum potential.

A better understanding through research of the risk factors that could contribute to injury rates within elite youth football and the impact that injury has on physical and psychological development at such an important stage of an academy football player's career, could help facilitate a player's development, reduce injury occurrences and improve the chances of them progressing to professional senior football.

Football injuries are related to numerous factors such as age, exercise load and playing standard (Hägglund *et al.*, 2005). Typically, the incidence of injury is highest in academy players within the under (U)18 age group, with adolescent players (17 to 19 years) being more vulnerable to injury when approaching the professional senior level (Brink *et al.*, 2010; Jones *et al.*, 2019; Price *et al.*, 2004; Read *et al.*, 2018a and b). Increased injury rates may be the result of a sudden and rapid increase in frequency and intensity of training and in competition loads, as players undertake full-time training and experience increased pressure to succeed and gain a contract (Brink *et al.*, 2010; Price *et al.*, 2004). Notably, elite youth academy players between 16 and 18 years (years) are more likely to be injured in training than players of other age groups between 9 and 15 years (Renshaw and Goodwin, 2016). Importantly, injury incidence during training for elite youth academy football players is higher than in senior professional footballers. The range of injuries in training sessions of academy players are 3.7 to 11.14 per 1,000 hours (h) of exposure compared to 1.37 to 5.8 injuries over the same exposure period in senior professional footballers (Pfirrmann *et al*., 2016). Renshaw and Goodwin (2016) suggested that higher training volumes could explain the higher injury incidence. This view is further supported by two studies on the prospective monitoring of Elite Player Performance Plan (EPPP) academy players to assess the effects of training schedules in different age groups, which attributed a greater injury rate to the higher training volumes within the U18 years group. Despite training and match loads not being measured, the authors acknowledge the importance of keeping track of training and match loads and having monitoring strategies in place to help mitigate injury risks (Read *et al*., 2018b; Tears, Chesterton and Wijnbergen, 2018).

It is widely accepted that sports injuries are a multi-risk phenomenon typified by interacting risk factors (Meeuwisse, 1994a and b). Many risk factors have been proposed as potential candidates to predict sport injuries (Meeuwisse *et al*., 2007). Some of these risk factors can be monitored using serial testing and modified to mitigate any risks and to monitor for physical development (e.g., Gabbe *et al*., 2004; Read *et al*., 2018a). The overall aim is to modify perceived issues *via* appropriate actions to reduce the likelihood of injury. Injury risk factors can be separated into two categories: internal (intrinsic) athlete related, which pre-dispose the athlete to injury, and external (extrinsic) environmental related; monitoring of both is standard practice in elite youth and senior football (e.g., Hughes *et al*., 2017; Lovell *et al*., 2019b; Read *et al*., 2018a). Intrinsic risk factors may be minimised by participation and adaptation to a graded exposure (extrinsic) to the competitive environment (Bowen *et al*., 2017; Meeuwisse *et al*., 2007). Injury prevention strategies aimed at reducing intrinsic risk factors address neuromuscular deficiencies such as, low levels of strength, reduced joint mobility, muscle tightness and slower impulse rates of motor neurons (Engebretsen *et al*., 2010a and b; Meeuwisse *et al*., 2007). In response, training and match exposure loads are monitored and carefully prescribed to players to help mediate extrinsic injury risks (Hägglund *et al*., 2013).

The EPPP programme was initiated to help develop youth academy players into elite senior first team players. Monitoring of academy football players for injury risks and physical development using measures for growth, physical fitness, exposure (training and match external loads) and injury surveillance i.e., the nature and rates of injuries (medical records), is embedded within the EPPP programme. A Premier League EPPP academy player is male and under contract within an U9 to U23 years age group. Individuals are registered, coached and play football at a club operating under designated Premier League audit rules. Players contracted full-time at a category 1 academy are defined as elite youth academy players. Some youth academy players are also under a professional senior contract but remain in the academy system and EPPP programme. The EPPP makes informed decisions based on monitoring to protect players from injury risks. However, the efficacy of current practices to monitor intrinsic and extrinsic risks from stress responses and neuromuscular impairment and how these relate to injury risk, remains unclear (Read *et al*., 2018a). Furthermore, the influence on player's physical and psychological development of time lost to train and compete as a result of injury is also uncertain. Nonetheless, it would be anticipated that a significant amount of time lost would negatively impair player's development (Jones *et al*., 2019). To date, monitoring both internal (intrinsic) and external (extrinsic) environmental risk factors in professional football has been dominated by measures of physical fitness (Buchheit *et al*., 2013). In contrast, psychological measures are often overlooked, despite the likelihood that they impact on physical fitness and ability to perform. Psychosocial variables in sport, such as stress, social support and coping influences, have a significant impact on injury risk and outcome (Williams and Andersen, 2007). An athlete's stress response is impacted by psychosocial stresses and previous injury research has identified interventions that could modify psychosocial risk factors (e.g., reducing stress, increasing coping strategies), with the aim of reducing injury occurrence (Williams and Andersen, 2007). Academy players are consistently placed in competitive and ‘stressful situations’ on a cumulative basis whilst trying to develop to become professional players (Saward *et al.*, 2020). At present, potential psychological measures are available to provide a more in depth understanding of an individual athlete to improve injury risk prediction (Ivarsson, Johnson and Podlog, 2013).

The analysis of data gained from multiple monitoring measures using an interdisciplinary approach should provide a better overall holistic picture of the injury risk factors to which a youth footballer is exposed and the changes to their physical and psychological development that injury occurrence could influence (Tobi and Kampen, 2018). Thus, sports practitioners can gain an insight into how best to predict improvement in specific areas such as physical fitness and exposure and how various measures can be used to create a desired effect on other aspects of physical performance and psychological well-being.

The overarching aim of this thesis was to assess the impact of non-contact injury on players’ capabilities to train and compete through an examination of relevant measures. These measures can be used in combination to monitor risk factors to injury, frequency of injury, physical development, and their effect on training and match availability within an EPPP academy. It is hoped that the data will be novel, insightful and informative to those supporting the development of elite youth footballers.

Chapter 2: Literature Review

2.0 Literature review

The following literature review aims to give an overview of the main aspects of the thesis. While most research literature searches focussed on academy football cohorts using predominantly Google Scholar and PubMed, research papers covering a range of other sports were also reviewed. These included studies on elite senior footballers and youth athletic cohorts similar to participants involved within this thesis (age range: 14 to 23 years). The research papers included within the thesis range from the years 1966 to 2021.

The sections covered include: supporting the development of academy footballers (2.1); an outline of the Elite Player Performance Plan (EPPP) (2.2), the blueprint for academy football in England and Wales; a review of injury within academy football (2.3), covering types and rates of injuries typically found within academy football. Injury risk factors associated with academy football (2.4) and how they are typically monitored. Current practices applied within academy football (2.5), which monitor growth and physical fitness development and exposure levels and their relevance to the impact of injury, and an assessment of psychological stressors (2.6), which are applicable to increased injury risk. Various developed dynamic models are detailed, which highlight risk factors leading to injury (Figures 2.1 and 2.5); the framework of the thesis was designed from these models. A summary of the aims and objectives is included (2.7).

2.1 Development of academy footballers

The development of academy footballers has always been considered important to elite footballing organisations, especially with the level of financial investment given by some clubs into their academy systems (Mills *et al.*, 2015). Football academies as well as national football associations identify, select and develop these players to an elite senior level (Williams and Reilly, 2000). The process involves highlighting players at a young age who are considered capable of becoming elite senior first team players, so that clubs are able to focus resources into their development. This creates the possibility of players being successful, resulting in a positive financial return of money for the club rather than buying already experienced expensive players (Williams and Reilly, 2000), and a positive outcome for the players who achieve their goal of becoming an elite senior footballer. Additionally, developing local players builds into the club's ethos and results in praise and attendance at games from their local fan base (Brandes, Frank and Nüesch, 2008).

Just over a decade ago, it was estimated that £40 million was invested into academies annually per elite club (Green, 2009). Since this report was published these investments are likely to have increased substantially. This investment has been built on by the Premier League through the EPPP (Online, Premier League, 2011) leading to increased financial investments and planning into player development by clubs. Increased competitiveness and investments places greater pressure on clubs and academies to have players available to compete and improve in physical performance in order to reach elite senior standards (Chamorro, Sánchez-Oliva and Pulido, 2019). If a player is not available to compete due to an injury, the club will suffer a high financial loss from medical costs and lack of return from investment (Hägglund *et al.*, 2013; Jones *et al.*, 2019). The significance of the impact of injury has translated to an expansion in research that uses approaches which are focussed on supporting player progression to an elite senior playing standard (Mills *et al.*, 2012; Mills *et al.*, 2014; Reeves *et al.*, 2009).

To select and develop young footballers, academies typically implement multi-dimensional approaches to help give context behind their players' development. These approaches include objective measures of growth, physical fitness, psychological and game specific skill factors (Reilly, Bangsbo and Franks, 2000; Reilly *et al*., 2000; Vaeyens *et al*., 2006). For example, the multidisciplinary approach proposed by Williams and Reilly was built upon a four-category model of possible predicting factors using an interdisciplinary approach and is specifically designed for highlighting talent within youth footballers for progression into future elite senior footballers (Williams and Reilly, 2000).

A high level of dedication is required by the individual player to progress to a higher level (playing standard) of academy football. Footballers spend a significant amount of time analysing their own performance and that of the team and opposition, training and competing to develop technical and tactical skills, physical fitness and psychological coping strategies (Read *et al*., 2018b; Saward *et al*., 2020). To accommodate education, training and competition, elite academy environments are designed to help create an atmosphere that aims to initiate and maintain high levels of dedication and commitment in players (Holt and Mitchell, 2006). When reviewing comparisons between elite and amateur footballers, various differences have been detailed such as deliberate practice time coordinated for players (U9 to U18 age groups) (Hornig, Aust and Güllich, 2016; Ward *et al*., 2007). However, one key critical variable in determining an academy footballer's chance of progression is whether they remain injury free and mitigating injury risk and occurrence within a football academy population is paramount. For example, in a study of French youth players, sustaining injuries that lasted more than 1 week was considered to negatively influence players' development to an elite senior level (Le Gall, Carling and Reilly, 2009).

2.2 Overview of the Elite Player Performance Plan

2.2.1 Constructs of the Elite Player Performance Plan

The EPPP is a development programme introduced by the Premier League in 2012 for English and Welsh football academies, designed to develop youth academy players into elite professional senior first team players and thus improve the number and quality of ‘homegrown’ players. The programme is designed to produce more elite players from the club’s catchment areas and, through individual player approaches, to give more responsibility to the individual player. Various principles were set out by the Premier League for the EPPP which are displayed in Table 2.1.

Table 2.1. Elite Player Performance Plan (EPPP) set principles.

Increase the number and quality of home-grown players gaining professional contracts in the clubs and playing first team football at the highest level
Create more time for players to play and be coached
Improve coaching provision
Implement a system of effective measurement and quality assurance
Positively influence strategic investment into the academy system, demonstrating value for money
Seek to implement significant gains in every aspect of player development
Allowing clubs to have more coaching time with their young players
Helping clubs foster links with local schools in order to help young players get the best out of their football education as well as the academic side
Allowing clubs that have earned a top category grading to recruit young talent from further afield than is permitted under the current rules
Working with the Football League to review the current system used for determining compensation

The EPPP programme has four principal sections: Games programme encompassing matches, festivals and tournaments; Education, to support players in multiple aspects of their development including technical, tactical, physical, mental and welfare; Coaching, and Elite performance, which includes tracking of information on performance and screening of injury, growth and maturation. Each football academy is categorised into various status levels in a four-tier system (1 to 4) with category 1 being the most elite. Indeed, in recent times, income has also increased within youth development systems for English and Welsh clubs. Each academy is audited independently by the EPPP with components such as training facilities, coaching and welfare provisions taken into consideration.

An EPPP academy player is under contract within an age group U9 to U23 years); age ranges are split into three phases: (U9 to U11), Youth Development (U12 to U16) and Professional Development (U17 to U23). Individuals are registered, coached, and play football at a club operating under designated Premier League audit rules. Players contracted full-time within the professional and youth development phase at a category 1 academy are defined as elite youth academy players; some youth academy players may be also under a professional contract, but remain within the academy system and EPPP programme.

2.2.2 EPPP- Elite performance

Elite performance (one of the four EPPP principal sections) involves a range of initiatives to inform awareness of player development, welfare and recruitment within a systematic evidence led approach. These programmes implement a multi-disciplinary platform using various components such as physical measures, relative age effects and psychological profiling. The programmes described below were implemented within this project using injury markers, fitness protocols and predicted growth and maturation insights.

An individual player's injury and rehabilitation processes are recorded using the same format across all twenty-seven category 1 clubs. All clubs input injury and illness data and their processes *via* the Premier League's performance management application (PMA) (The Sports Office, UK). Though the descriptions of injury and illness remain consistent across clubs, descriptions of injury occurrence may differ.

Within the EPPP, national benchmark fitness testing sessions are run through designated periods of the season, and all of the tests implemented are performed by players from U12 to U23 age groups. All clubs are provided with the same standardised equipment for each testing session. Each physical test remains consistent across each club and members of the Premier League (external to the academies) assist with some of the testing sessions.

Growth and maturation measures are used consistently across academies consisting of various anthropometric measures (Read *et al*., 2018a). These measures are used primarily to prevent age becoming an influencing factor in preventing players' development and progression (Patel, Nevill and Smith, 2019; Patel *et al*., 2019). Initiatives include implementing bio-banded games (Cumming *et al*., 2018) and reviewing other aspects such as playing position which could be influenced by growth changes at younger ages (Towlson *et al*., 2017). It has also been recommended that using growth and maturation monitoring of elite youth footballers can help alleviate injury risk and improve player development (Kemper *et al*., 2015; Read *et al*., 2016), by identifying players with increased growth rates in a short space of time (van der Sluis *et al*., 2014) and modifying their internal and external workloads accordingly, so they can adapt appropriately (Read *et al*., 2016).

2.2.3 EPPP- Performance requirements

Monitoring growth, physical fitness and exposure of academy football players allows academies to make informed decisions with the aim of protecting academy players from injury and to scrutinise and support their development. Previously published injury rates within EPPP footballers have indicated the importance of efficient monitoring provision (Read *et al*., 2018b; Tears, Chesterton and Wijnbergen, 2018). The efficacy of selection and standardisation of some testing protocols of monitoring measures used and their associations to injury occurrence within elite youth footballers remains unclear (Read *et al.*, 2018a)

Table 2.2. Number of hours coaching contact time per week required in each development stage for each EPPP academy category.

Academy Category	**Foundation Phase (FD)**	**Youth Development Phase (YDP)**	**Professional Development Phase (PDP)**
Category 1*	4 - 8 h	10 - 12 h	12 - 14 h
Category 2*	3 - 5 h	6 - 12 h	12 - 14 h
Category 3	3 h	4 - 6 h	12 h
Category 4	n/a	n/a	12 h

FD, (U5 to U11); YDP, (U12 to U16); PDP (U17 to U21).

*Hours based on a 40-week season. From U15 upwards, hours are based on a 46-week season (The Premier League, 2011). n/a, not applicable; h, hours.

One performance indicator set out by the EPPP (2011) includes a designated weekly training time requirement, which differs according to phase of the academy (Foundation-Professional) and level of category (1 to 4) (Table 2.2). This initiative was based on the principle of a 10,000 h prediction; once a certain period of practise is completed elite standards are obtained.

The professional development phase's contact time remained similar to the previously used programme from FA Charter standards of 12 h per week (Wilkinson, 1997). This is significantly higher in comparison to standard practice time of elite senior first team players, where typically (~4 h) of weekly training volume is implemented by elite senior teams during in-season competition to maintain or increase physical performance capacity (Anderson *et al*., 2016). The practise time of the foundation and youth phase players is increased substantially with the development pathway doubling their training time. Despite the requirement for such high amounts of designated training times, academies have been recorded as having reduced the amount of these set training times with reports of U18 players completing ~5 h training in weekly micro-cycles with one competitive fixture, within the season (Enright *et al*., 2015; Malone *et al*., 2015a). This raises the question of whether these designated training times are necessary and if the training time is misjudged. The balance between the level of intensity required in elite youth football to improve performance and robustness could be outweighed by the length of pitch-based training time required. Hence, higher training times (higher training volume) may be excessive for youth footballers. Instead, an appropriate (lower) amount of time spent training may be sufficient to improve (Ericsson, 2013). However, it could also be argued that maximising training time is necessary for players to develop technically.

From a physiological performance perspective, it is necessary to determine what optimal training stimulus is required for players to produce the most beneficial training response (Impellizzeri, Rampinini, and Marcora, 2005). Targeted training volumes could be optimised by EPPP academies by taking direction from modern research aimed at establishing the optimal training volume for elite youth players to improve performance intensity whilst mitigating fatigue and injury risk (Noon *et al*., 2015; Read *et al*., 2018a and b). It would be interesting to review the effectiveness of this research by comparing indicated training volume to player progression and/or injury occurrence (Read *et al*., 2018a and b). Training volumes, performance and injury risk comparisons in youth athletes could be made to other sports. Youth athletes exceeding 16 h of training volume per week have had increased risk of injury occurrence (Rose, Emery and Meeuwisse, 2008). There is also evidence that early specialisation coupled with intensive training can result in overuse injuries (Jayanthi *et al.,* 2015). Psychological factors such as anxiety, burnout and depression have also been associated with youth athletes specialising in a single sport at an early childhood/ adolescent age (Brenner, 2007; DiFiori *et al*., 2014; Mostafavifar, Best and Myer, 2013). It may not be appropriate to compare training and injury levels between different sports because of the variations in physical components such as load, technical, bio-mechanical demands and in support systems and stressors associated with competitive standards. Additionally, early intensive specialisation for academy footballers may be necessary, to ensure they adapt to the high skill demands that are required to progress to an elite senior level.

Category 1 EPPP academies require various types of equipment to monitor external workloads and other physical performance variables. This equipment, such as global positioning system (GPS) devices, requires financial investment to be endorsed by academies. Specific testing protocols for growth and physical fitness are set by the EPPP, with both being testing periodically. Growth testing involves systematic data collection across all phases of development within the EPPP and incorporates growth and maturation equations, involving a cross-validated predictive algorithm from implementing anthropometric measures of: standing stature (height), seated stature (height) and leg length (Mirwald *et al*., 2002; Parr *et al*., 2020). Fitness testing is completed and advised by the Premier League with a standard battery of testing measures including counter movement jumps (CMJ), linear sprints and the 505-agility test. While these measures are required within EPPP academies, it would be insightful to review other available monitoring methods and their relationships to components of injury, progression in performance and playing standard to provide a more holistic monitoring approach. This in turn is more likely to identify factors affecting all of these components (e.g., Reilly *et al*., 2000; Williams and Andersen, 2007).

2.3 Overview of injury in academy football

2.3.1 Injury prevalence associated with academy football

A recent systematic review detailing injury incidence in academy footballers found high frequencies of injury occurrence within a regular, youth football season (Jones *et al*., 2019). According to the injury definition (minimum 48 h post event) (Read *et al*., 2018a and b) non-contact injuries accounted for 66% (median) of all total injuries in U9 to U21 age groups. The review also showed that players had reduced playing development opportunities in both training sessions and matches during the season as a result of these injuries and observed that UK-based players experienced longer absences from training and competition (Jones *et al*., 2019). Injury incidence during training for elite youth academy football players is higher than in senior professionals and the range of injuries in training sessions is 3.7 to 11.14 per 1,000 h of exposure, compared to 1.37 to 5.8 injuries over the same time period as senior professional footballers (Pfirrmann *et al*., 2016). Higher training volumes could explain the higher injury incidence in elite youth footballers. As such, 181 elite youth academy players from the same EPPP academy within the age band 16 to 18 years (6 / 1000 h) were more likely to be injured in training than players of age groups between 9 to 15 years (lowest age group, U9 to U11: 0.69 / 1000 h) (Renshaw and Goodwin, 2016). Two studies reported on the prospective monitoring of elite academy players to assess the effects of training schedules in different age groups. The first examined 608 players aged 11 to 18 years from six EPPP academies throughout the 2014/15 season (Read *et al*., 2018b). The second investigated the injury incidence and patterns in elite youth football at one category 1 Premier League academy over six years (seasons) encompassing pre- and post-introduction of the EPPP (Tears, Chesterton and Wijnbergen, 2018). In at least one academy, following the introduction of the EPPP, injury incidence was reduced in the U12 to U15 age group, but the severity of injuries increased in the older U16 to U18 group. A significantly greater incidence rate of player injury was observed in the U18s playing squad (229 total injuries) compared to other younger age groups (U11 to U16) (53 to 116 total injuries) (Read *et al.,* 2018b). The published evidence attributes the greater injury rate to the higher training volumes undertaken by the U18 year age group within the EPPP. Matches are associated with an injury risk five-times higher than during training in elite youth footballers (Ergün *et al*., 2013; Le Gall *et al*., 2006). Typically, match play accounts for most injuries and this has been reported in various studies with the percentage of total injuries, ranging from 51% (Deehan, Bell and McCaskie, 2007) to 66% (Bacon and Mauger, 2017). Within a single category 1 EPPP academy over two consecutive seasons, non-contact injury occurrence was greater in matches (7.9/ 1,000 h) compared to training (5.6/ 1,000 h) (U18 to U23 age groups; 17.3 ± 0.9 years, stature 180 ± 7.3 cm, body mass 74.1 ± 7 kg) (Bowen *et al*., 2017). Match injury occurrences for players within U18 to U21 year age groups (Bianco *et al*., 2016; Ergün *et al*., 2013) were equivalent to elite senior players' injury occurrences (8.0 to 65.9 per 1,000 h exposure) (Eirale *et al*., 2012). These findings highlight the importance of monitoring the physical demands of training and matches and having weekly monitoring strategies in place in the build-up to matches, to help prevent injury, especially when physical performance demands are high (Read *et al*., 2018a and b). A comparison of injuries in a single category 1 academy prior to, and after, introduction of EPPP strategies showed that 6% of injuries were reoccurring injuries (Tears, Chesterton and Wijnbergen, 2018). Within a large cohort of youth footballers (U12 to U18 age groups) injury history was concluded to have a high association with a risk of injury reoccurrence. Players sustaining one previous injury had a twofold higher risk of injury occurrence (IRR = 2.6; 95% CI 2.0 to 3.3) and a threefold higher risk of injury with two or more previous injuries (IRR = 3.0; 95% CI 2.3 to 3.8) in comparison to players with no previous injuries (Kucera *et al*., 2005). Analysis of the severity of injury of elite youth players showed that 40% of recurrent injuries that players sustained resulted in longer training withdrawal than their original injuries (Le Gall *et al*., 2006). Recurrent injuries were more frequent in training and in at least one study all the recorded recurrent injuries were overuse injuries (Ergün *et al*., 2013). Although, the higher injury rates associated with older adolescents (16 to 19 years) may stem from various factors, research tends to emphasise the higher volume and intensity of training required at this age. Yet rarely are the training and match loads and intensity published, albeit that collecting and analysing workload accurately over a longitudinal period can be a difficult task, especially when the investigator is external to the club. Additionally, modifiable limitations have been acknowledged when observing injury audits. For example, the number of staff monitoring and recording exposure and injury data can vary, potentially resulting in bias. This can be addressed by using standard operating procedures (SOPs). Also, external validity could be enhanced by increasing the number of academies observed at one time, where all practitioners are working to SOPs. Mitigating these limitations in injury research would be beneficial to all concerned within the academy system including researchers.

Pre-season periods are a critical period for an elite youth footballer to attain sufficient physical attributes and capacities in order to cope with the competitiveness of the on-going season (Jeong *et al*., 2011). It has been suggested that the pre-season phase within an elite youth football structure is not long enough to prepare players to sustain the loads brought about throughout the season, resulting in an elevated injury occurrence

(Ekstrand *et al*., 2019). This, and sustaining a greater amount of fatigue without adequate recovery time, are two factors that could lead to the higher injury rate within the pre-season phase (Price *et al*., 2004; Read *et al*., 2018a). January is also highlighted as a phase of increased injury occurrence in elite youth football (Le Gall, Carling and Reilly, 2007; Price *et al*., 2004; Read *et al*., 2018a) and again this may be related to a break from training. Within EPPP competitive seasons the off-season and Christmas period are the only extended periods of rest. The Christmas period (~2 weeks) has been highlighted as a possible reason for an elevated injury occurrence period within January (Jones *et al*., 2019), with too short an extended period of rest to allow for sufficient recovery in a physically and psychologically demanding, lengthy season. A limitation of exposure-related injury studies is that they have focussed mainly on senior male professional footballers (eg., Dauty and Collon, 2011; Ekstrand, Hägglund and Waldén, 2011). These studies are of limited relevance to youth players because of the different stages of physical and psychological development, and the differing physical demands and characteristics between senior and youth players. Therefore, an examination is justified of the relationship between exposure-related injuries and the effects of load spikes with inadequate rest within elite youth footballers. Also, there are currently few equivalent injury reports that examine the combined physiological and psychological stress demands placed upon academy football players and how they respond to, and cope, with these demands (Brink *et al*., 2010; Ergün *et al*., 2013).

2.3.2 Types of injury within academy football

Observing and defining the anatomical sites of non-contact muscular injuries can be problematic due to inconsistent definitions used throughout research (Jones *et al*., 2019). Similar to most team invasion sports, the lower limb is the most common site for injury within youth football (Price *et al*., 2004; Read *et al*., 2018a and b). Comparisons have been drawn to injuries sustained by elite professional senior players with the hip, groin, and posterior thigh all being highlighted frequently within the literature (e.g., Ekstrand, Waldén and Hägglund, 2016; Jones *et al*., 2019; Thorborg *et al*., 2014a and b). However, injury rates of a specific anatomical site can vary between studies involving elite youth footballers. The thigh has been cited as the most common anatomical site for injury by Renshaw and Goodwin, (2016), whereas other researchers have identified the ankle and knee as the most common injury sites (Junge, Chomiak and Dvorak, 2000; Peterson *et al*., 2000; Read *et al*., 2018a and b), or groin and lower limb (Deehan, Bell and McCaskie, 2007; Fuller *et al*., 2006). Whilst Price and colleagues reported approximately equal injury incidences for the thigh (19%), ankle (19%), and knee (18%) (Price *et al*., 2004).

Muscle strain injury occurrences account for 37% (median of 2346 reported cases in 7953 players) of all injuries reported within youth football (Jones *et al*., 2019). An example of the prevalence of muscle strain injuries in EPPP academies is shown within the injury audit conducted by Read and colleagues, muscle strain injuries (162 total injuries, 20.9 % of total injuries) were the highest type of injuries sustained across a season (Read *et al.,* 2018b). Muscle strain injuries are categorised into four different grades of increasing damage severity (Grades 0 to III inclusive), with severity corresponding to increased time loss from physical activity (Peetrons, 2002). Grade 0 (observable tissue damage) and Grade I (tears) are associated with microscopic tears (oedema without fibre damage) which can lead to some loss of function. Grade II equates to fibre damage and Grade III is classified as a complete rupture of the muscle resulting in loss of function (Blankenbaker and Tuite, 2010; Peetrons, 2002). The grading of each muscle strain injury equates to an estimated and confirmed return to play.

HSI are very common across all levels and age groups of footballers (e.g., Ekstrand, Waldén and Hägglund, 2016; Henderson, Barnes and Portas, 2010; Price *et al.*, 2004) and the demands of running are related to these injuries (Hawkins *et al.*, 2001; Woods *et al.* 2004). The vast majority of HSI (80%) relate to the biceps femoris muscle (BF) (Arnason *et al.*, 2004; Askling *et al.*, 2007; Silder *et al.*, 2008) when an individual dynamically lengthens in an aggressive motion in the terminal swing phase of sprinting (Chumanov, Heiderscheit and Thelen, 2011; Schache *et al.*, 2009; Thelen *et al.*, 2005). Characteristically, acute pain in the posterior thigh is experienced, which usually results in time lost from competition and training (Verrall *et al.*, 2001; Woods *et al.*, 2004). Ekstrand and colleagues observed exposure to, and playing time lost, due to HSI over a four-year period in professional football players. Lay-off time in days Total: 19 ± 17 Grade 0: 8 ± 3, Grade I: 17 ± 10, Grade II 22 ± 11, Grade III: 73 ± 60, with Grade I injuries being the most frequent (57% of all occurrences) (Ekstrand *et al.*, 2012). Each HSI usually results in ~17 days without training and competition for players in professional football (Ekstrand, Waldén and Hägglund, 2016). Regardless of the severity of the injury, any time absent from match play and training can have a detrimental impact on an academy footballer's career progression because of a loss of playing time and evidence of increased susceptibility to future HSI injuries (Verrall *et al.*, 2001). In addition, HSI, like any injury, can have detrimental effects on both individual and team performance, and player development, as well as the financial feasibility of elite sport clubs with an estimated ~ £280,000 per injury (Ekstrand *et al.*, 2013).

The most commonly injured structures in an athlete are the lateral ligaments of the ankle (DiGiovanni, Partal and Baunhauer, 2004), as demonstrated in EPPP footballers (Read *et al.*, 2018b). Across two EPPP seasons within U18 to U23 age groups of a single academy the ankle/foot anatomical area had the highest-level occurrence of non-contact injuries (2.1/1,000 h) (Bowen *et al*., 2017). However, there is limited research focussing directly on ankle injuries and their association to injury risk factors within elite youth footballers; most research has focussed on the frequency of occurrence and the impact on lost playing and training time (Cloke *et al*., 2009; Read *et al*., 2018b). Both prospective and retrospective studies have investigated an extensive list of possible risk factors for foot and ankle-ligament sprains including a prior sprain, gender, stature and body mass (weight), limb dominance, foot anatomy and size, the ankle anatomy and ankle-joint laxity, the dynamic range of movement (DROM) of the ankle-foot complex, postural sway and the strength and reaction time of muscle (Beynnon, Murphy and Alosa, 2002; Fong *et al*., 2007). The key risk factors highlighted within professional players were age (younger) and ankle instability (Fousekis, Tsepis and Vagenas, 2012). A previous sprain of the ankle-ligament complex is the most often studied factor because any trauma of a ligament degrades a key biomechanical stabiliser and causes limited deafferentation of the ankle (Beynnon, Murphy and Alosa, 2002; Fong *et al*., 2009). It is unclear from the literature whether a previous sprain poses a risk for a future sprain; intuitively though, this would seem to be correct (Beynnon, Murphy and Alosa, 2002). Conversely, at least one study showed that previous injury to the ankle was not associated with a repeated ankle injury within elite senior footballers (Hägglund, Waldén and Ekstrand, 2006). What is clear, however, is that ankle injuries are regular and have a major impact on playing availability within elite youth footballers. Monitoring of players, aged 11 to 18 years, from 6 academies across an EPPP season revealed that the most significant injury sites were knee (161 injuries; 20 % of total injuries) and ankle injuries (147 injuries; 18.3 % of total injuries) (Read *et al*., 2018a and b); when each player sustained at least one injury they missed twenty training days and two matches per season (Cloke *et al*., 2009).

Long term groin injuries can result in significant time-loss from sport (Bradshaw, Bundy and Falvey, 2009), high rates of reappearance (Tyler *et al*., 2001) and decreased function (Weir *et al*., 2011). Groin pain in elite youth footballers is a common issue and it is prominent for being a complex issue that can be attributed to various disorders, few of which are well defined (Malliarias *et al*., 2009; van Klij *et al*., 2020). The Doha Agreement Meeting on terminology and definitions for groin pain in athletes concluded an agreement on a clinically based taxonomy with three groups: 1. Defined clinical entities for groin pain: adductor-related, iliopsoas-related, inguinal-related and pubic-related groin pain; 2. Hip-related groin pain and; 3. Other causes of groin pain in athletes (Weir *et al*., 2015). Groin injuries are poorly defined and lack clear analytical criteria, furthermore, they are predisposed to chronicity and recurrence (Crow *et al*., 2010). Extensive differences between possible injuries at various anatomical structures, their high occurrence and often asymptomatic nature in athletes complicates the problem further (Weir *et al*., 2015). To prevent groin injuries from occurring it has been suggested that early identification is required for optimal management, with groin pain being a part of the continuum of pathology (Rodriguez *et al*., 2001), for which treatment can also be problematic (Verrall *et al*., 2005a and b). It is also noted that prescribed stimuli of adductor strengthening interventions can reduce groin injuries, as the hip, groin and pelvic regions undertake morphological adaptations which can result in youth players being predisposed to injury 'risk' (Harøy *et al*., 2019a, b and c; Tak, *et al*., 2015). Interventions aimed to help prevent injury risk will be examined in greater detail below.

2.4 Injury risk factors in academy football

Risk factors can be separated into two categories: internal (intrinsic) athlete related risk factors and external (extrinsic) environmental risk factors. Intrinsic risk factors pre-dispose the athlete to injury, and are important determinants of load tolerance, for example, the mechanical properties and size of a ligament are influenced by age, sex, body size and training background (Bahr and Krosshaug, 2005). Exposure to extrinsic risk factors (such as type of sport, amount of training, training environment and equipment) makes a pre-disposed athlete susceptible to injury (Hägglund *et al*., 2013; Stege *et al*., 2011). Therefore, highlighting an athlete's pre-disposed risks prior to activity allows for appropriate risk management through prescribed optimal corrections before any intense, lengthy exposures. It also allows for adequate recovery to be introduced, so that any pre-disposed risks are not aggravated further (Brink *et al*., 2010; Laux *et al*., 2015; Read *et al*., 2018a). These studies underline the importance of preventing injury and protecting player welfare in the development of young footballers and as such, it is becoming common practice to determine the health and fitness status of these players *via* monitoring the intrinsic and extrinsic risk factors that impact upon chronic fatigue and injury (e.g., Arnason *et al.,* 2004; Dvorak and Junge, 2000; Dvorak *et al.,* 2000; Junge, 2000; Kucera *et al*., 2005; Le Gall, Carling and Reilly, 2007; Price *et al*., 2004; Schwebel, Banaszak and McDaniel, 2007).

Risk factors, in turn, can be divided into modifiable (can be controlled) and non-modifiable (cannot be controlled e.g., age) factors (Meeuwisse *et al*., 2007). It is important to monitor and prescribe correct interventions for risk factors that can be modified and minimised as an elite youth footballer participates and adapts to a graded exposure of the competitive environment (Bowen *et al*., 2017). Coaches and practitioners will look to expose players to demanding physical and psychological stimuli for them to achieve the greatest adaptations, tolerance, and coping strategies to deal with the stressors associated with elite football (Akubat, 2012; Bowen *et al*., 2017; Saward *et al*., 2020). This can be achieved through injury prevention strategies aimed at reducing intrinsic risk factors since they often seek to address deficiencies in physical fitness, joint mobility, muscle tightness and/or weakness, motor abilities and sports specific skills proficiency (e.g., Engebretsen *et al*., 2010a and b; Fousekis, Tsepis and Vagenas, 2012; Meeuwisse *et al*., 2007; Orchard, 2001). By monitoring and prescribing exposure levels and intensity (extrinsic risks) such as training load (TL), players can achieve physiological adaptations whilst minimising the risk of injury (Bowen *et al*., 2017; Impellizzeri, Rampinini, and Marcora, 2005; Meeuwisse *et al*., 2007).

Non-modifiable risk factors, such as age, may provide greater insight when examined against the type and severity of injury. Such information will inform injury prevention techniques and rehabilitation processes (DiStefano, *et al*., 2009). Therefore, it is vital to gain a holistic view on the cause of injuries, and the mechanisms by which they occur, to have a better chance of minimising any injury risk (Bahr and Holme, 2003). A dynamic model of aetiology in sports injury has been developed that explains that a player with intrinsic risk factors may be exposed to extrinsic risk factors repeatedly through multiple participations, but not suffer a sports injury. They may even adapt to the exposure extrinsic risk factors to increase their tolerance and reduce their risk of injury. Any injury sustained, may not necessarily represent a finite endpoint whereby the individual is permanently removed from participation (Meeuwisse *et al*., 2007). Monitoring both internal (intrinsic) and external (extrinsic) environmental risk factors has become an established practice in elite youth and senior football. However, at present this process is dominated by measures of physical fitness (e.g., Buchheit *et al*., 2013; Casajús, 2001; Reilly and Doran, 2003) such as monitoring for HSI risks. HSI is a common injury sustained in elite football that is relatively easy to monitor with sophisticated, reliable monitoring tools (e.g., Arnason *et al.,* 2004; Opar *et al.,* 2013; Woods *et al.,* 2004).

Research on the relationship between psychological factors such as stress, and injury in elite senior and academy players is sparse, despite psychological measures being emphasised as beneficial to identify psychological stressors and recovery rates in footballers (Kucera *et al.,* 2005; Laux *et al*., 2015; Price *et al.,* 2004;). Determining whether the contribution of psychological factors is correlated with injury occurrence, resulting in a loss in playing availability for training and matches, would provide a novel insight into injury prevention (Laux *et al*., 2015). Research to date has identified influences of a psychosocial nature, including stressful life events, somatic trait anxiety, mistrust, and ineffective stress coping, that can contribute to an elevated injury risk in academy football players (Johnson and Ivarsson, 2011). Overall, there is a lack of research surrounding psychological parameters to monitor and highlight injury risk, and to determine the long-term effects on player development (Sarmento *et al*., 2018).

An adapted version of Meeuwisse's model (Meeuwisse *et al*., 2007) was designed to help with the framework of the thesis (Figure 2.1) that incorporates psychological factors from the stress and injury model by Williams and Andersen (Williams and Andersen, 2007), (Figure 2.5). This 'revised' model provided a conceptual framework for Studies 1 and 2 (Chapters 4 and 5) (without added psychological risk factors) and Study 3 (Chapter 6) (with added psychological risk factors). Table 2.3 outlines examples of common internal and external risk factors for sports injuries, some of which will be monitored within the current project.

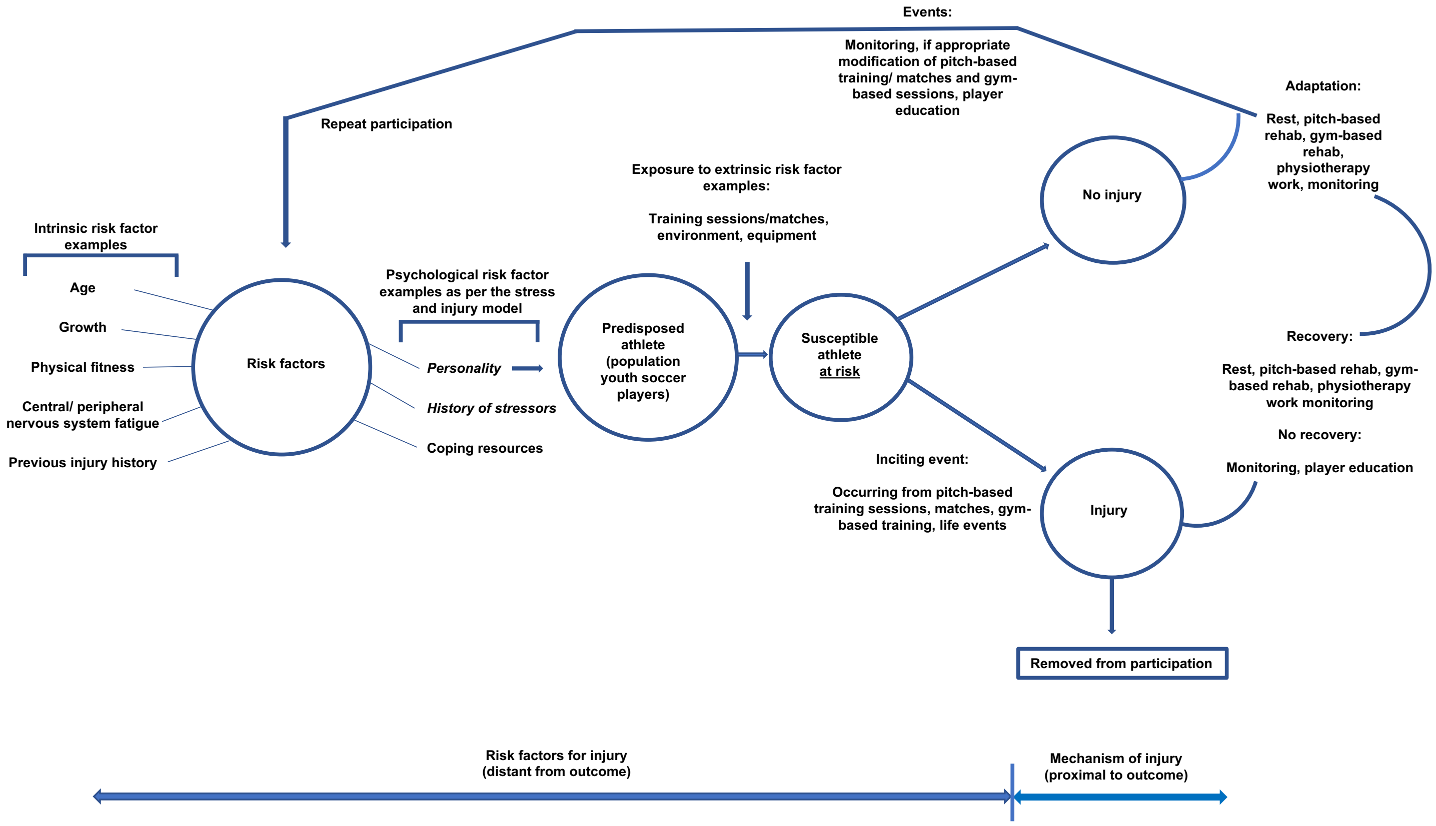

Figure 2.1. A dynamic, recursive model of aetiology in sports injury. Adapted from Meeuwisse *et al*., (2007) through specific risk factors, added psychological factors (Williams and Andersen, 2007) and various components which relate specifically to the processes of an academy youth football player.

Table 2.3. Extrinsic and intrinsic risk factors for sports injuries.

Adapted from (Taimela *et al.*,1990; van Mechelen, Hlobil and Kemper, 1992).

Extrinsic risk factors	Intrinsic risk factors
Exposure	*Physical characteristics*
Exposure time	Age: Date of birth
Playing position	Body composition
Level of competition	Previous injury history: Injury data
	Physical fitness
Training	Joint mobility, imbalance
Type	Muscle tightness and weakness
Training specification	Strength, imbalance
Volume	Central and Peripheral nervous system fatigue
Intensity	
	Psychological profile
Environment	Motivation
Type of playing surface	Risk taking
Indoor/outdoor	Stress coping
Time of season	Personality
	Stress states

2.4.1 Monitoring injury risk factors

The pre-season is commonly used as a period to identify intrinsic risk factors for sports injury in sporting environments including medical, growth and physical fitness assessments (functional and performance) (Bourne *et al.*, 2020; Chalmers *et al.*, 2018; Hughes *et al.*, 2020), although these tests can be replicated through the season (McCall *et al.*, 2015). Tests to identify intrinsic risk factors for injury which are applied by sporting organisations, are typically formulated from clinical and practical experience and based on published literature (Gabbe *et al.*, 2004). As stated previously, since injury risks to the lower limb are of primary concern within a football environment (e.g., Price *et al.*, 2004;

Read *et al.*, 2018a and b), testing batteries for football clubs are designed to specifically examine these lower limb anatomical sites.

However, future research utilising applied testing batteries could examine upper-limb related risks, which would be more relevant to specific positions such as goalkeepers (GK). Researchers have examined movement patterns and multiple tests of function, such as strength and range of motion (ROM), alongside limb asymmetries, to highlight individual risk factors efficiently and accurately (Plisky *et al.*, 2006; Wollin *et al.*, 2018). The multiplicity of screening tests (medical, functional, performance based) has helped to identify injury risk, and have informed innovative developments such as, the use of prognostic models which plot injury risk against pre-season screening measures using a decision-curve analysis (Hughes *et al.*, 2020). When developed further, this novel method could be applied within football environments to monitor for injury risk.

It has been stated that the outcomes of training are anatomical, physiological, biochemical and functional adaptations which are relevant to the specific sport (Viru and Viru, 2000). However, it could be argued psychological adaptations could also occur. Training adaptations are crucial for performance requirements to be achieved and can be determined through multiple monitoring methods (see section 2.5). Appropriate balances between training, competition and recovery are necessary because of the extensive stressors and playing demands placed on players to maximise performance and mitigate injury risks. These can be optimised by monitoring approaches (Akubat, 2012). Load monitoring for elite sporting teams is used extensively to assess an athlete's readiness for competition and performance development in part through the monitoring of TL (Anderson *et al.*, 2016; Rogalski *et al.*, 2013). Across competitive seasons monitoring individuals training load (Scott *et al.*, 2013), can include internal (Foster *et al.*, 2001) and external load measurements (Boyd, Ball and Aughey, 2013; Farrow, Pyne and Gabbett, 2008). TL can be described as an input variable, and controlled to produce an anticipated training response (Impellizzeri, Rampinini, and Marcora, 2005). Dose(load)-response (performance, fitness, fatigue) relationships need to be considered to achieve this and to minimise injury risk (e.g., Akubat, 2012; Impellizzeri, Rampinini and Marcora, 2005). An example of how TL affects training responses is detailed within the 'Training Process' by Impellizerri, Rampinini and Marcora, 2005 (Figure 2.2).

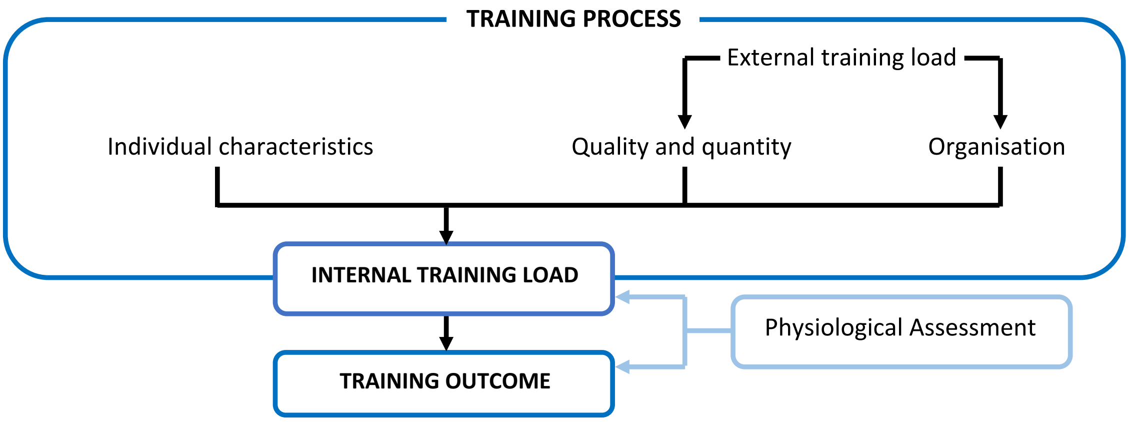

Figure 2.2 Overview of the training process.

This model details how training and the characteristics of an individual combine to form the internal TL and subsequently the training outcome for that individual.

Taken from Impellizerri, Rampinini, and Marcora, 2005.

Similar to the adapted model of Meeuwisse *et al*., (2007) 'A dynamic, recursive model of aetiology in sports injury', the 'Training process model' (Impellizerri, Rampinini, and Marcora, 2005), indicates that individual characteristics should be accounted for alongside external exposure. The Training process model details that internal load represents the training outcome and characteristics of an individual combined with external TL influence internal TL. The stimulus for adaptation is the physiological internal load stress placed on the athlete and not external load (Viru and Viru, 2000; Impellizerri, Rampinini and Marcora, 2005) and monitoring all the components of the training process, as detailed in the model, is necessary to examine dose-response relationships effectively (Akubat and Van Winckel, 2014). This requires a pro-active approach, as training outcome is evaluated typically from injury occurrence or a physical fitness monitoring tool e.g., Akubat and Van Winckel, 2014). Also, physiological adaptation processes are not fixed and could be influenced by aspects such as fatigue and/or risk of infection which play significant roles in the performance of academy footballers; without sufficient recovery time athletes underperform, lose playing time and risk injury (Budgett, 1998).

Rejuvenation of cellular responses is needed for appropriate recovery and for adaptation to occur (Budgett, 1998). Therefore, consideration should be given to the times when training outcomes are monitored. For example, monitoring training outcomes at specific times within the season, such as during a period of congested matches, may not be suitable (e.g., Akubat, 2012; Banister, 1991). Appropriate levels of recovery from external load exposure can help mediate the effect of higher workloads which can aggravate physical discrepancies in players resulting in injury risk; however, psychological stressors (discussed in Section 2.6) within individuals can also impair recovery processes (Brink *et al.*, 2010).

In football, there is an emphasis on use of the stretch shortening cycle (SSC) of the muscle unit, consequently muscle force production and power are significant (Thomas, French and Hayes, 2009). Therefore, measurement of rapid force development would be beneficial. The demands of elite football induce neuromuscular fatigue of peripheral mechanisms (skeletal muscles) necessitating several hours of recovery

(Rampinini *et al*., 2011). Combined with heavy resistance training performed in a dynamic exercise-induced method, participation in elite football results in greater exercise induced fatigue, muscle damage, sarcomere disruption, force loss of myofibrils (Panchangam and Herzog, 2012), hormonal effect, impaired excitation-contraction coupling metabolic metabolism and demand (Izquierdo *et al*., 2009). To cater for a player in the current environment, it is important to monitor neuromuscular and peripheral mechanisms since there is a link between muscular fatigue and injury (Enoka, 2002), biochemical impacts and adaptations of the musculoskeletal system to overtraining, resulting in decreased performance (Dugan and Frontera, 2000).

A recent examination into the practices and perceptions for injury prevention at EPPP academies concluded that while approaches to mitigate injury risks were rational, through the inclusion of screening measures such as strength and flexibility measures, they were not based sufficiently on current research (Read *et al*., 2018a). When employing measures to monitor injury risk and performance it is important that they are validated, reliable, and suitable for the testing environment e.g., the equipment and testing protocol for any given measure needs to be able to collect data accurately and keep the players engaged (maximum input of effort). Also, any testing protocol has to fit within the weekly schedule used for build-up to competition without causing disruption and creating further risk of injury to the individual, e.g., performance of a strength measure that does not allow appropriate recovery time before intense activity, or aggravates a player's previous injury. Much can be learned from testing results and the application of testing findings that can help reduce injury risk. An example is the identification of asymmetry or imbalance between limbs which might place the footballer at risk (e.g., Croisier *et al.,* 2008). Importantly, establishing how each measure can be applied to identify injury risk is required. Confirmation as to which measures are appropriate requires multiple tests and examination of their relationships with respect to various levels of injury risk.

2.5 Current monitoring practices in academy football

In order for a youth footballer to progress to a higher playing standard, they must achieve a sufficient standard of physical development due to the physical demands of elite football (Barnes *et al.*, 2014; Le Gall *et al.*, 2010). To monitor development of both growth and physical fitness, various measures are applied within elite football academies (Le Gall *et al.*, 2010; Reilly, Bangsbo and Franks, 2000; Reilly *et al.*, 2000). These measures can determine how players are developing naturally, whether the stimuli to which they are exposed are promoting effective adaptations, resulting in high availability for training and matches, improved performance (Brink *et al.*, 2010; Buchheit *et al.*, 2010a and b) and whether the player has reached physical development (growth, fitness) associated with an elite senior standard (Le Gall *et al.*, 2010). In turn, the volume and intensity of training and match exposure can be examined to see if players are exposed to an adequate level of load to promote physical development and remain injury free (Brink *et al.*, 2010; Bowen *et al.*, 2017). What is positive, is that many of the measures which can be applied to monitor physical development (intrinsic) and exposure (extrinsic) can be applied in unison to monitor injury risk in youth footballers (e.g., Brink *et al.*, 2010; Read *et al.*, 2018a and b).

2.5.1 Growth

Systematic growth testing, including anthropometric measures of stature (standing and seated) and body mass, are typically employed within all elite sporting environments. Growth measures are used to review many parameters such as, relative age effects, maturation and as a marker of individual growth of players within EPPP growth testing protocols (Patel *et al*., 2019). Other measures have been implemented within various sporting environments to establish growth adaptations such as analyses of skeletal tissue and bone breadth (Janssens, Van Renterghem and Vrijens, 2001). Measures such as air displacement plethysmography and skinfold testing can be used. However, some of these growth measures are costly, such as the air displacement plethysmography, and therefore may not be available within the majority of elite sporting organisations. On the other hand, skinfold testing is cost-effective and is used within elite youth football (Le Gall *et al*., 2010). However, if testing protocols are valid and performed correctly (Munguia-Izquierdo *et al*., 2018) they can be lengthy and hard to implement repeatedly within weekly timetable structures. Stature and body mass are universally used measures to establish growth adaptations in elite youth football (e.g., Kemper *et al*., 2015; Le Gall *et al*., 2010; Patel *et al*., 2019), being both time and cost effective.

The influence of anthropometric differences in association with injury occurrence in elite youth footballers has been investigated. Regular anthropometric monitoring of elite youth footballers has been identified as helpful when highlighting injury risk factors: growth in stature (≥ 0.6 cm, per month); increased body mass index (≥ 0.3 kg/m^2, per month); and a low body fat percentage (< 5%) within a group over 16 years of age (n = 101) from the same academy (Kemper *et al*., 2015). An adolescent's peak height velocity (PHV) involves a significant increase in accelerated speed of maturation and growth rates typically within a short range of time. PHV in youth footballers is associated with a high injury rate (Van der Sluis *et al*., 2014). Various physiological symptoms including amplified stiffness of anatomical joints and muscular skeletal tissue are common when an adolescent male is going through a period of maximal growth and is believed to be the reason behind an amplified rate in injury occurrence paired with maturation and growth rates (Read *et al*., 2018a; Van der Sluis *et al*., 2014). Specific changes include increased joint stiffness of the hip, knee and ankle (Ford, Meyer and Hewett, 2010), and a reduction in flexibility in the back and hamstrings (Philippaerts *et al*., 2006).

Growth and maturation measures have also been highly influential in helping to highlight players who have not reached their peak level of maturation from a performance perceptive. Such measures have been implemented by the Premier League to ensure that players who have not yet reached PHV are not excluded from progressing further within academy development centres. This is because growth differences contribute to the probability of players progressing to a higher standard of football, with heavier and taller players being more likely to progress (Le Gall *et al*., 2010). For example, it has been reported that category 1 academies preferentially select players exhibiting more advanced maturity characteristics, compared to players within academies from lower-league teams in the UK (Patel *et al*., 2019). When 426 players (Premier League First Team, U9 to U23 age group squads within a category 1 EPPP academy) were monitored across the 2010/11 to 2017/18 seasons, height was recognised as an important characteristic for selection (Patel *et al*., 2019). It has been highlighted that youth Australian footballers (U11 to U19 age groups) who are more mature, may have a performance advantage against those who do not. Significant correlations in greater training and fitness performance were demonstrated with more biologically and/or chronologically mature players, through measures of running fitness and running performance (Gastin, Bennett and Cook, 2013). The same bias to maturity levels is also shown in position allocation, with relative age, maturation and anthropometric characteristics giving preference to players within defensive positions: GK and centre back (CB) positions have taller and heavier characteristics (likely small to very-likely moderate effects) and matured to a greater extent within the U13 to U14 age groups (very-likely small to likely moderate effects).

Positional-specific physical attributes in outfield players are not established until a later period in their talent development (Towlson *et al*., 2017).

Assessment of a player's growth changes, and predictive growth allows for controlled interventions, understanding and guidance to be implemented, in order to prevent injury and/or help with players' development (Van der Sluis *et al*., 2014).

2.5.2 Physical fitness

For youth footballers to perform and progress with the necessary levels of competitiveness within match-based environments, they require technical and tactical skills, physical capacity and performance attributes, to be able to physically cope, remain injury free and to maintain or increase cumulative performance outputs (Hulse *et al*., 2013). Overall, developing a youth footballers' athletic performance involves improving a multitude of physiological aspects all considered important in reducing injury risk (Read *et al.,* 2016; Reilly *et al.,* 2000). Examples of physical performance attributes associated with this include fitness involving aerobic, anaerobic systems (Silva, Nassis and Rebelo, 2015) and neuromuscular strength (Timmins *et al*., 2016a and b). As the demands of physical fitness in elite youth footballers are becoming greater (Gonaus *et al*., 2019) it is important to apply reliable monitoring procedures that can determine whether development (e.g., training outcome) is occurring. Typically, within elite footballing environments monitoring procedures are set out to best evaluate movements and those performance attributes which are translatable to field-based play (Deprez *et al*., 2015; Huijgen *et al*., 2014; Loturco *et al*., 2014). Monitoring procedures that involve systematic fitness assessments are completed throughout a football season to review adaptational changes (Reilly, 2005) and these have been greatly valued in football academies (Paul and Nassis, 2015).

With youth footballers, fitness components of sprint speed, change of direction speed, vertical jump height and endurance have all been highlighted as important physical fitness characteristics (Buchheit *et al*., 2010a and b). Therefore, a battery of fitness tests created by the EPPP to measure these fitness components is employed by their academies to measure fitness development (Online, Premier League, 2011). These fitness components have also been shown to predict a higher playing standard and future career advancement (Cometti *et al*., 2001; Le Gall *et al*., 2010; Murr, Raabe and Höner, 2018). When comparing amateur, professional and international footballers, direct associations have been shown between an elite youth footballer's probability of progressing to a higher standard of football from fitness-based assessments of CMJ and 40 m linear sprint (Le Gall *et al*., 2010). Disparities in sprint and jumping performance have been demonstrated between elite senior and youth footballers (Sporis *et al*., 2009), though differences between the levels of standard and age may be due to methodological issues upon data collection (Rumpf *et al*., 2011).

Similar to growth as outlined earlier, physical fitness biases of individuals within EPPP academies have been shown to carry over to the designation of playing position, e.g., outfield players in the later talent development stages in the EPPP (Professional stage) displaying position-specific physical fitness attributes (Towlson *et al*., 2017). These physical fitness variances have also been shown between different playing positions in youth footballers outside the EPPP (Buchheit *et al*., 2010b; Sporis *et al*., 2009).

Though sprinting and change of direction tests have demonstrated associations to injury (Chalmers *et al*., 2013) they are not typically employed by academies to monitor injury risk. Instead, batteries of tests are employed to examine strength, flexibility and efficiency of movement (e.g., Newton *et al*., 2017; O'Brien, Santner and Finch, 2018;

Wollin *et al.*, 2018), which are also used to monitor neuromuscular status (Claudino *et al.*, 2017; Rey *et al.*, 2016) and physical performance development. These measures can be performed acutely within microcycles of the season or longitudinally, for example, in the pre-season and at the end of a season (Noon *et al.*, 2015). Whilst the EPPP programme instructs with respect to some monitoring measures for growth, physical fitness and exposure, it is the academies themselves that determine internally what are the best other measures to be employed, at what stage during the season they are used and when in the weekly build up to matches.

2.5.2.1 Strength

One focus of the current research project is the search for ways to reduce injury occurrence. Researchers have examined specific movement patterns to predict injury risk factors and it has been hypothesised that employing a battery of tests involving multiple aspects of function, such as strength, leads to greater accuracy in highlighting individual risk factors to injury (Plisky *et al.*, 2006). Strength can be modified through specific physiological adaptations using prescribed conditioning that may lead to reductions in strain injuries within muscle groups such as the hamstring (Petersen *et al.*, 2011), hip and groin (Harøy *et al.*, 2019a, b and c; Ishøi *et al.*, 2018). Examples of various strength related intrinsic risk factors include agonist/antagonist muscle ratios for strength and endurance, structural musculoskeletal abnormalities and contralateral muscular imbalances (Witvrouw *et al.*, 2003). Since athletes are exposed to multiple risk factors, specific screening tests are commonly used in different sports to highlight those risk factors related to muscular strength (Callaghan and Jarvis, 1996; Gabbe *et al.*, 2004; Tanner and Gore, 2013).

Hip, groin and HSI within senior football have been the focus of extensive research since these are common injuries (Thorborg, *et al.*, 2014a and b; Timmins *et al.*, 2015; Werner *et al.*, 2009). In comparison, youth football populations have to date received less attention, perhaps because of the need to determine injury risks within senior players based on the higher levels of investment. However, this may change with the increasing levels of investment in elite youth players. Strengthening specific muscle groups by applying appropriate guided conditioning is considered influential within injury prevention and physical development programming which can be achieved by implementing specific muscular strength measures (Bourne *et al.*, 2017a and b; O'Brien and Finch, 2016). Common muscular injury anatomical sites in youth footballers can be targeted, which centre predominantly around the lower limbs, and in particular the thigh, groin, ankle and knee (Le Gall *et al.*, 2006; Price *et al.*, 2004; Pfirrmann *et al.*, 2016; Read *et al.*, 2018a and b; Thorborg *et al.*, 2014).

2.5.2.2 Techniques for measuring hamstring strength

It has been hypothesised that inter-relating multiple risk factors may cause HSI (Hoskins and Pollard, 2005; Mendiguchia and Brughelli, 2011). Since the aetiology of HSI is multifactorial, inadequate hamstring muscle strength (Opar, Williams and Shield, 2012a and b), imbalance of strength in the hamstring muscles between limbs, and a history of any previous hamstring injuries (Arnason *et al.*, 2004; Croisier, 2004; Engebretsen *et al.,* 2010a; Hägglund, Waldén and Ekstrand, 2006; Verrall *et al.*, 2001) are examples of important risk factors for monitoring and preparing professional footballers (Buckthorpe *et al.*, 2019). Reduced lower limb and eccentric hamstring strength and muscle strength imbalances were also identified as relevant injury risk factors in a recent review for players in the EPPP (Read *et al.*, 2017).

Levels of hamstring eccentric strength have been shown to have an association to HSI; lower levels of strength increase HSI risk in senior professional footballers (Croisier *et al.*, 2008; Timmins *et al.*, 2016a and b) and previous HSI has an impact on hamstring eccentric strength on senior Australian footballers (Opar *et al*., 2015a and b). Since HSI have been associated with low levels of eccentric knee flexor strength in footballers (Timmins *et al*., 2016a and b) measurement of eccentric knee flexor strength may identify those footballers at risk of future HSI (Opar *et al*., 2014; Timmins *et al*., 2016a). For example, across the 2014/15 season, professional footballers with lower levels of eccentric knee flexor strength (n = 96) were 4.4 (RR = 4.4; 95% CI = 1.1 to 17.6; *p* = 0.013) times more likely to develop a HSI than stronger athletes (n = 35) (Timmins *et al*., 2016a). Therefore, increasing eccentric muscle strength has been proposed as an important factor for offsetting the risk of HSI, *via* prescribed interventions, alongside correcting strength imbalances and improving flexibility (Bourne *et al*., 2018; Opar, Williams and Shield, 2012a and b). The NHE can be included within hamstring intervention programmes and has been shown to improve eccentric knee flexor strength and to reduce injury risks (Mjølsnes *et al*., 2004). Furthermore, it is the best supported exercise in the literature for the prevention of HSI (e.g., Arnason *et al*., 2008; Petersen *et al*., 2011). Large scale interventions that utilise NHE have demonstrated ~65% reductions in HSI and eccentric training allows for protective benefits for footballers (Arnason *et al*., 2008; Bourne *et al*., 2016; Petersen *et al*., 2011). Recent systematic reviews and meta-analysis examining the consequences of NHE on hamstring injury rates in football players concluded that teams that had incorporated NHE within injury prevention programmes decreased hamstring injury rate by 51% longitudinally in comparison to those that did not (Al Attar *et al*., 2017; Cuthbert *et al*., 2020; Van Dyk *et al*., 2019). Most HSI occurrences in adult footballers have been shown to involve the biceps femoris long head (BFLH) (Ekstrand, Hägglund and Walden, 2011; Woods *et al*., 2004), which suggests that hamstring injury prevention programmes should target the BFLH specifically and engage the BFLH fascicles (Bourne *et al*., 2015; Opar *et al*., 2014). There is evidence of an increased risk of HSI in elite senior footballers when they have low eccentric knee flexor strength levels and short (in length) BFLH fascicles (Timmins *et al.*, 2016a and b). Both the NHE and the hip extension (HE) exercises have been demonstrated to improve the lengthening and promote hypertrophy (and therefore strength) of BFLH fascicles (Bourne *et al.*, 2017a and b). The two exercises have been shown to act in different ways highlighting the heterogeneity of the muscle fibres within the hamstring. The NHE develops the semitendinosus (ST) and the short head of the biceps femoris (BFSH) preferentially, whereas HE training increases hypertrophy in the long head BFLH and semimembranosus. Both exercises generate elongation of the BFLH and help to improve eccentric hamstring strength (Bourne *et al.*, 2016; Bourne *et al.*, 2017a and b; Bourne *et al.*, 2018).

The NHE has been frequently highlighted in the literature compared to HE when applied to elite footballers (Timmins *et al.*, 2016a and b). A potential barrier to use of the NHE is that when players are unaccustomed to performing the exercise, they may experience muscle soreness (Bahr, Thorborg and Ekstrand, 2015). However, this observation requires further examination, especially as compliance to prescribed programmes involving NHE, notably in-season, are sometimes infrequent. Two studies have demonstrated this low compliance of players, although both did not find a significant association between prescribed NHE protocols and hamstring injury rates (Engebretsen *et al.*, 2008; Gabbe, Branson and Bennell, 2006). Low compliance may also be due to the demand on footballers to play multiple matches with short 'turn-arounds' of recovery. Others have suggested that intense bouts of running (such as sprinting) with a greater increase in muscle tendon unit length (Chumanov *et al.*, 2007) and predominantly concentric muscle action conditioning, may impair the anticipated benefits of NHE (Askling *et al.*, 2007; Ekstrand *et al.*, 2012; Woods *et al.*, 2004). Recently, it has been demonstrated that sprint training has more of an effect on lengthening BFLH than NHE in footballers (Mendiguchia *et al*., 2020).

The timing (prior to, and post football pitch-based training sessions) of NHE application has also been shown to affect architectural adaptations of eccentric hamstring strength (Lovell *et al*., 2018). Using NHE testing to measure increases in BF fascicle length in 72 amateur footballers (age: 23.6 ± 4.7 years) identified a greater increase prior to training (+1.58 cm; 0.48 to 2.68 cm; small effect) than post training. While hypertrophy responses of muscle thickness (+0.17 cm; 0.05 cm to 0.29 cm) and pentation angle (+1.03°; -0.08° to 2.14°) were greater from NHE testing post-training compared to testing prior to training (Lovell *et al*., 2018). Timing of the NHE could help target specific hamstring architectural adaptations, for example by employing the NHE post training to help promote greater hamstring hypertrophy of the BF fascicle (Lovell *et al*., 2018), which can enable greater force production of the musclo-tendon unit (Blazevich *et al*., 2007). However, it is difficult to generalise because of differences between organisations in cohorts, training exposure, training effects, age groups and playing standards. The influence of fatigue within players post training and the timing of the season should also be taken into consideration, as mental and physical fatigue, depletion of muscle glycogen stores and branched amino acids could affect factors such as application of effort of players when performing the exercise (Brownstein *et al*., 2017; Mohr *et al*., 2008).

Eccentric and concentric asymmetry testing has been introduced *via* isokinetic dynamometry to determine limb hamstring strength imbalances within elite football environments. This type of testing evaluates unilateral and bilateral hamstring strength and predicts an increased risk of HSI when a footballer displays an asymmetry of ≥ 15% (Croisier *et al.,* 2008). However, the use of isokinetic dynamometry testing in football academies is limited due to the financial costs of the equipment and the lengthy time needed for testing protocols. An alternative to this typically laboratory-based assessment is the measurement of forces obtained while an athlete performs an NHE, using the NordBord, which is designed specifically to measure eccentric knee flexor strength. The NordBord hamstring testing system was developed to screen hamstring strength effectively and efficiently. The Nordbord's hamstring strength measurements determines eccentric knee flexor strength *via* peak Nordic force (NF) and between-limb force asymmetry and demonstrates high to moderate levels of test-retest reliability during bilateral testing of elite athletes (Opar *et al.,* 2013). Analysis of eccentric knee flexor strength employing the device has been applied before in field-based testing and protocols for its use have been described (e.g., Opar *et al.,* 2013; Opar *et al*, 2015a and b; Timmins, 2016a and b). The NHE is the most proficient means of dealing with problems of eccentric knee flexor strength movements associated with HSI in football (Almeida, Maher and Saragiotto, 2018) and NHE use can reduce both first and recurrent strains (Petersen *et al*., 2011; van der Horst *et al*., 2015). Information gained from eccentric strength measures is valuable for risk management of future HSI.

2.5.2.3 Techniques for measuring adductor and abductor strength

The primary strength measure to examine groin pathology is an adductor (groin) strength test. This is typically used to indicate a player's adductor muscle activity and strength levels (Engebretsen *et al.,* 2010b) which are linked with groin pain (acute and chronic) and hip rotation (Nevin and Delahunt, 2014). The test involves dynamic bilateral isometric hip adduction and can also be utilised as both an indirect measure of abductor strength and hip joint range of movement (ROM) (Nevin and Delahunt, 2014). During hip adduction, five muscles can be activated, all of which have been highlighted to contribute to sporting injuries: pectineus, adductor brevis, adductor longus, gracilis and adductor magnus (Sinnatamby, 2003). Commonly used positions to measure adductor strength include 0, 45, 60 and 90 degrees (°) flexion of the hip and knee (Delahunt *et al*., 2011; Lovell, Blanch and Barnes, 2012; Ryan *et al*., 2019). In one study of 21 elite youth footballers, adductor strength tests were conducted at various test positions (supine position: flexion of the knee and hip, 0°, 45°, 90°; hips 0° force exerted at the ankle; hips 70° one limb flexed; side lay, straight leg raised) and their association with adductor muscle activation analysed (Lovell, Blanch and Barnes, 2012). Although the pectineus muscle was activated best at 90° flexion of the knee and hip, 0° and 45° were more preferable flexion positions with adductor muscles being active as well; whilst 0° recorded the highest force output and 45° showed the highest electromyography output (*via* electrode placement) (Lovell, Blanch and Barnes, 2012). Comparisons of 0 °, 45 °, 90° flexion of the knee and hip have also demonstrated that 45° displays the lowest minimal detectable change, standard error of measurement and measurement percent (Delahunt *et al*., 2011).

In the majority of adduction strength tests, the force of adduction is measured with the participant in a supine position, with the medial femoral epicondyle aligned to exert force (short lever position), though there are exceptions such as conducting the test standing, sitting or laid on one side, or exerting force *via* ankles (long lever position) (Lovell, Blanch and Barnes, 2012). Typically, within the literature, three trials at maximal exertion are collected for each test and practice trials are required prior to any maximal effort being completed (Delahunt *et al.,* 2011; O’Brien, Santner and Finch, 2018). Each trial requires the participant to apply force isometrically from adduction of the hips until their peak force is reached (Delahunt *et al.,* 2011). Specification of the recorded trials for analysis can differ between studies with some combining scores to equate the average (Delahunt *et al.,* 2011), and some recording the maximal score (O'Brien *et al*., 2019). Difficulties could arise when trying to obtain three maximal efforts due to the fatigue-rate especially if participants are not familiarised with the test. Therefore, recording at least one maximal effort may be the priority. Also, it is not beneficial to measure multiple efforts of any physical test if a participant demonstrates discomfort after one maximal effort. This is due to the likelihood of maximal scores being affected and the possibility of creating a greater muscular issue such as a strain. After each adductor strength test, participants can be asked if they experience pain when performing each trial, and if so, on which side they experienced the pain, or whether on both sides. This can help to determine if there are underlying muscular issues (Delahunt *et al*., 2011; Nevin and Delahunt, 2014). Adductor groin pain has symptomatic links to multiple dysfunctions such as a hernia, nerve entrapment, hip joint pathology adductor strains and tendinopathies (Hölmich, 2007; Werner *et al*., 2009). Groin pain is common in academy footballers (Light *et al*., 2018) and underreported in football organisation's injury data records since footballers can typically continue to play and train through it. A reduction in adductor strength leads to both groin pain and groin strains within youth footballers (Engebretsen *et al*., 2010b; Esteve *et al*., 2018). Therefore, early identification and reporting would be beneficial (O'Brien *et al*., 2019).

Abductor strength is also considered to be a useful measure for the purpose of screening youth footballers to identify those more likely to suffer future hip and groin pain (Thorborg *et al*., 2018). Ratios in relative strength levels between hip adduction and abduction measures can be considered when monitoring for injury risk and groin pain in elite youth footballers (Thorborg *et al*., 2011; Wollin *et al*., 2018). Findings have demonstrated that hip adduction strength (unilateral) should be equal to its contralateral side (Thorborg *et al*., 2018) and that a significant risk factor of groin injury is a strength ratio of hip adduction-to-abduction that is less than 80% (Tyler *et al*., 2001). This has been further underlined by a study monitoring 100 elite youth footballers' rehabilitation following a groin strain injury, in which it was acknowledged that achieving equal adductor strength levels of both sides of the groin (injured and non-injured) and an abduction-to-abduction ratio of 90 to 100% would be desirable for a successful return to play (Thorborg *et al.*, 2011).

2.5.2.4 Techniques for measuring vertical jump

Vertical jump performance can be measured using various types of equipment and technologies. Typically used field-based equipment include yardsticks (Leard *et al.*, 2007), linear position transducers (Cronin, Hing and McNair, 2004), photoelectric cells (Glattorn *et al.*, 2011) and contact mats (Garcia-Pinillos *et al.*, 2015). All can be transported easily and are suitable for measuring jump height within sporting environments, but are limited in the number of variables they can record. In comparison, force plates, have a high accuracy and range of variables which they can record (Cronin, Hing and McNair, 2004), but they are costly and can be large in size making them harder to transport. However, smaller portable force plates have now been designed which are more accessible and suitable for field-based testing. They can also be partnered dually to measure impulse differences between limbs. However, similar to non-portable force-plates they can range in robustness and quality, with the higher quality specifications being more expensive.

Effective and efficient locomotion is underpinned by how a footballer uses the SSC of the muscle units and consequently produces significant muscle force and power (Thomas, French and Hayes, 2009). Based on the importance of the SSC function to locomotion and performance, measurement of force development would be a useful guide for the physical development of academy footballers.

The CMJ (measured *via* force platforms) can monitor eccentric and concentric force outputs effectively (Hart *et al.*, 2019), which in turn have direct associations to the

SSC (Loturco *et al*., 2015; Toumi *et al*., 2004a and b). The CMJ is regarded as a slow-SSC movement (> 250 ms in duration), specific to sprint acceleration and is associated with possible movement patterns within football matches (Cronin and Hansen, 2005). The CMJ test is commonly used to monitor acute and longitudinal changes of athletic and neuromuscular performance within sporting and research environments, being implemented in a reliable and time efficient manner (Halson, 2014; Heishman *et al*., 2019; Menzel *et al*., 2013).

The CMJ has been compared frequently to the drop jump (DJ) (Thomas*,* French and Hayes, 2009), although the movement demands are different in how force production is applied; the DJ redirects an initial force, whereas the CMJ requires force production to be initiated from a static position (Coh and Mackala, 2013; Earp *et al*., 2011). Both CMJ and DJ have been shown to improve jump and short sprint performance (Bissas and Havenetidis, 2008). The DJ is considered to be more inclusive as a measure of fatigue *via* the SSC (Raastad and Hallen, 2000), while the CMJ is effective when measuring neuromuscular fatigue (Taylor *et al.,* 2012). Testing protocols for the DJ can vary: the height from which to drop (starting phase) and whether to jump or lead with one foot or two (Delahunt, Monaghan and Caulfield, 2006; Whyte *et al*., 2018). Dependent on the equipment being used, the CMJ, like the DJ, can measure factors of unilateral movements and force production when jumping and landing (Lake *et al*., 2016) all of which have relevance to injury risk in elite youth footballers (Daneshjoo *et al*., 2013; Read *et al*., 2016).

2.5.2.5 Techniques for measuring flexibility

Flexibility is considered to be the aptitude of a muscle or muscle group to lengthen, which is affected by muscular, connective and neural tissue (Nordez *et al*., 2017). The impact of reduced muscle flexibility in certain movements for footballers can limit the ability to perform specific technical football skills efficiently and therefore affect performance (García-Pinillos *et al*., 2015; Mills *et al*., 2015). Flexibility and joint range of motion (ROM) are significant practical components with respect to the functionality of performance. Impairment, from stiffness of muscle tendon units (Mizuno, Matsumoto and Umemura, 2013), can result in a reduction of performance (Hatano *et al*., 2019) and can increase the risk of muscle strain injuries (Witvrouw *et al*., 2003). Research by Gabbe and colleagues has highlighted reliability when completing simple clinical measures of ROM and flexibility. Also, there is support in the literature for the use of certain tests, such as a sit and reach test as a pre-participation to activity screening measures for athletes (Gabbe *et al*., 2004). If individuals are subjected to testing over just a short window of time, it can allow for reliable and effective monitoring to inform the individual and enable collective decisions by medical and sports performance staff. As with all testing, keeping flexibility testing as standardised as possible is necessary for reliability, since factors, such as the time of day in which testing occurs, can influence testing results (Guariglia *et al*., 2011).

The design of flexibility measures used within a battery of tests requires careful consideration. The use of numerous measures of flexibility and their sequence in a testing battery can impact negatively on test reliability when employed within an EPPP category academy cohort (n = 75, age 12–20 years) (Grazette *et al*., 2020). These researchers questioned whether the timing of testing and/or the effort required by participants to perform the multiple tests affected the reliability, or if the measures themselves were unreliable. Since the validity and reliability of all the measures had been demonstrated previously, it was interpreted that the order and amount of flexibility measures that should be used in a single testing battery were important. Thus, it could be essential to reduce the number of flexibility measures in a battery of tests to only the most informative and reliable. Also, how relevant they are to test specific movements that have an influence on non-contact injury risk or indicate injury 'risk' (Grazette *et al*., 2020).

Some flexibility measures require multiple examiners when performing test protocols. For example, utilising hand-held measurement apparatus such an inclinometer, tension meter or a goniometer to measure the ROM of various joints through ranges of flexion and extension (Arnason *et al*., 2004). In contrast, some measures require just one individual examiner to record the test which the participant can perform without assistance. From a practical viewpoint, implementing flexibility measures within elite sporting environments which do not require the same, or more than one examiner, to record the test, are easily performed, replicated and are the optimal choice as the examiners can be kept consistent over longitudinal periods and between test-error can be mitigated. To ensure standardisation and external validity for flexibility measures, it is critical that no contrasting movements or exercise, including stretching are performed prior to completing each of the tests.

Given the prevalence of lower limb injury in youth footballers, measures of specific joint flexibility targeting anatomical areas associated with injury risk may be of higher importance for EPPP academies. Recent EPPP injury audits indicated the highest number of injuries and ligament sprain injuries were sustained within the anatomical sites of the ankle (65%) and knee (32%) (Read *et al*., 2018b). Strength measures as shown above can highlight weakness and imbalances within anatomical locations at risk of injury such as the hamstring and groin which could lead to muscle and ligament strains (Read *et al*., 2018a). Flexibility measures can provide additional information to help mitigate injury risk by measuring flexibility ranges of the motion of those specific anatomical areas most associated with injury risk, such as ankle dorsiflexion (Witvrouw *et al*., 2003).

The dorsiflexion range of motion (DROM) of the ankle can have an effect on a number of foot and ankle injuries, including diagnosed ankle arthrosis and chronic ankle instability in jogging (Denegar, Hertel and Fonseca, 2002; Drewes *et al*., 2009; Landrum *et al*., 2008; Khazzam *et al*., 2006; Youdas *et al*., 2009). Increased DROM is associated with a reduction in knee pain within movement patterns which involve the kinematics of the knee (Macrum *et al*., 2012); but prior to the design of any remedial actions, it is important to clarify how the clinical assessment of an injury relates to DROM. Posterior talar glide joint mobilisation techniques and the performance of static stretching of the triceps surae complex 1 have produced some success in increased DROM (Landrum *et al*., 2008; Vicenzino *et al*., 2006). The dorsiflexion lunge/ knee to wall test has been promoted as it is quick and easy to apply, and the protocol for the test can be replicated within a sporting environment in repeated-measures screenings (Esmaeili *et al*., 2018; Malliaras *et al*., 2009). As such, it is commonly implemented as a monitoring tool of the ankle. Dorsiflexion can be measured in both lower limbs *via* a lunge test alternating the leading limb against an even levelled wall (Bennell *et al*., 1998), or with a handheld measurement device such as an inclinometer (Witvrouw *et al*., 2003). Measuring dorsiflexion using a tape measure, digital inclinometer and goniometer have all demonstrated high to moderate reliability (Konor *et al*., 2012), with digital inclinometer and tape measure protocols demonstrating higher reliability (ICC = 0.96 to 0.99) than the goniometer (ICC > 0.85).

Hamstring flexibility has been identified as another key factor in monitoring athletes. Reduced extensibility and flexibility in the hamstring muscles could lead to lower back pain, further predisposing players to muscle injuries (Henderson, Barnes and Portas, 2010; Jones *et al*., 2005). Amongst elite senior footballers (n = 36, age 22.6 ± 5.2 years), the risk of sustaining a HSI has been shown to increase 1.29-fold from a decrease in primary active range of hip flexion (Henderson, Barnes and Portas, 2010), highlighting the general interrelating risk of lack of flexibility in other body areas including the hip. Interventions that apply hamstring flexibility protocols have been used extensively by professional football clubs (Dadebo, White and George, 2004; Hatano *et al*., 2019). HSI rates have been highlighted as a significant injury issue within elite football (Arnason *et al*., 2004; Woods *et al*., 2004) such as within the English Premier League (M13.3 (SD 9.4)/1,000 h per injury). In professional football, hamstring stretching is one of the most important training interventions associated with Hamstring Strain Rate ($p = 0.031$), as highlighted by the interventions of flexibility protocols (Dadebo, White and George, 2004).

Hamstring flexibility can be determined by numerous measures. The 'straight leg raise' (Medeiros *et al*., 2016) and the 'sit and reach test' are two of the most frequently reported in the literature and are used extensively within elite youth football (Read *et al*., 2018a; Vandendriessche *et al*., 2012) to measure flexibility (extension) of the hamstring muscle (Hartig and Henderson, 1999). The straight leg raise requires one or two testers to be present to measure the hamstring range of both limbs with either a goniometer or an inclinometer. In addition, recent research has determined that the Functional Movement Screen (FMS) straight leg raise test does not measure hamstring flexibility efficiently in footballers (n = 101; age, 21 ± 3 years; stature, 179 ± 7 cm; body mass, 75 ± 9 kg) when compared to a passive straight leg raise flexibility measure using an inclinometer (Medeiros *et al*., 2019). This is due to the small range of categorical scoring (0 to 3), which does not capture sensitive flexibility differences; but due to the nature of the test it may not be ideal for monitoring screenings over a short period of time (Medeiros *et al*., 2019). The sit and reach test is the most established and commonly used screening measure within sporting environments which can be implemented on a daily basis and has demonstrated excellent intra-tester reliability. It requires a custom-made sit and reach box and uses a scale (cm) for scoring quantification (Gabbe *et al*., 2004). In contrast, the sit and reach test is not a valid method when determined *via* a hand-held inclinometer (Youdas, Krause and Hollman, 2008a and b). Protocols for this test are easy to apply and no tester is required to assist with the movement, only to record the test. However, one disadvantage of the sit and reach is that unilateral flexibility cannot be assessed.

2.5.3 External and internal load

Monitoring load (exposure) of training and matches has become a characteristic phenomenon within elite football, largely because of increasing levels of intensity due to physical and technical demands (Barnes *et al*., 2014). Increased physical fitness and work capacity standards have translated across to the elite youth level from senior professional football. Volume and intensity, which are used together to monitor training and match loads, are the two central components which are implemented and controlled within cumulative training sessions. Load can be split into two components of external and internal load (Impellizzeri, Rampinini and Marcora, 2005). External load can represent physical activities which the individual completes (an extrinsic factor) such as, training sessions and matches, whereas internal load represents physiological responses from the external stressor (an intrinsic factor) and can be quantified as an output of exercise duration and intensity (Booth and Thompson, 1991; Vahia *et al*., 2019).

The model created by Vanrenterghem and colleagues to monitor TL in team sports presents a framework in which physical actions performed by a footballer (characterised as external load) are distinct from physiological and biochemical stresses (defined as internal load) leading to adaptation of the athlete (Vanrenterghem *et al*., 2017). This model serves to understand how external and internal load measures can be introduced and balanced to monitor both physiological and biomechanical adaptations relevant to fitness and fatigue levels in individual team players where load-adaption pathways vary (Vanrenterghem *et al*., 2017). Training and match loads (both external and internal) are then reviewed and revised following the implementation of various measures within elite youth football to improve performance whilst preventing injury (Vanrenterghem *et al*., 2017; Weston, 2018). Within elite football external load measures are commonly paired with those for training intensity from an internal load perspective (Vahia *et al*., 2019) particularly within training sessions (Dellal *et al*., 2010). This serves to monitor prescribed workload set by coaches and practitioners to identify training responses and changes in fitness capacity for individual players (Wallace, Slattery and Coutts, 2009). It also offers a way of monitoring TLs to help mediate onset and effects of fatigue (Halson, 2014) and changes within fitness capacity (Brink *et al*., 2010).

2.5.3.1 Techniques for measuring external and internal load

Current examples of external monitoring systems integrated within elite football include local positioning systems and semiautomated cameras. However, GPS is the most commonly applied system to monitor and quantify external training and match loads objectively from time–motion analyses, with benefits of real-time monitoring, quick data processing and feedback (Bowen *et al*., 2017; Hewitt, 2014). This information can be used to prescribe specific TLs modifying them according to intensity, duration and playing frequency applicable to match demands for individual players, and/or their particular positions (Cummins *et al*., 2013). EPPP category 1 academies are expected to carry out load monitoring across pro-phase age group squads (U17 to U23) for the purposes of monitoring training and match activities (Malone *et al*., 2015b). This includes a requirement for EPPP academies to use validated GPS devices to measure external loads within U23 and U18 age group squads to maintain category 1 status.

GPS devices are assessed on their ability to monitor and quantify various external load movements and velocities accumulated by each individual player (Coutts and Duffield, 2010). Utilisation of GPS is multifaceted, from interpreting analyses and consequently managing physical stressors appropriately, optimal prescriptions of stimulus over controlled durations can be appropriately assigned to players, consistently facilitating aspects such as physical capacity (Kellmann, 2010). It is acknowledged, that despite the requirement for external load monitoring, research examining the associations between injury ‘risk’ and physical loads is at an initial stage (Bowen *et al*., 2017).

GPS devices record player workloads from total distance covered, time/distance and a range of velocities including peak velocity (Hewitt, 2014). Devices calculate distance and velocities *via* positional differentiation or Doppler-shift (Malone *et al*., 2017). From a satellite-based feed, global positions and movement patterns are determined on satellite locks (SL). When monitoring sports specific movements, a GPS requires at least four satellite feeds to give an efficient signal to an area in which the GPS device can operate, the size of which is dependent on specification of the satellite (Hewitt, 2014). Multiple aspects need to be reviewed in order for SL feeds to acquire accurate data. These include synchronicity, the receiver unit, signalling errors, atmospheric conditions, mask angle and ephemeris error. For example, receiver units with < 6 SL connections can result in a weaker connection (Bacci *et al*., 2012; Steede-Terry, 2000), with received unit travel speed being influenced by positional differentiation or Doppler-shift (Larsson, 2003). For satellite connection, global positioning of the devices is derived from the GPS device using a calculation of the total time signal from numerous satellites, calculating position *via* distance to devices. Connection errors can occur when the device and satellites are not in sync, and timings cannot be determined reliably (Hewitt, 2014). Staggered uploads recalibrating times between satellites and devices can be applied, reducing possible acute errors of one upload, though error risk can increase over time (Conley *et al.*, 2006). The restriction of satellite feeds to GPS devices from external objects is defined as mask angle. In a sporting context, this could be a large stadium, as demonstrated within Figure 2.3 (Hewitt, 2014). Due to these factors, GPS devices requiring a satellite feed are not likely to be used within a closed (roofed) environment, or a large enclosed stadium, in the satellite feed could be blocked potentially.

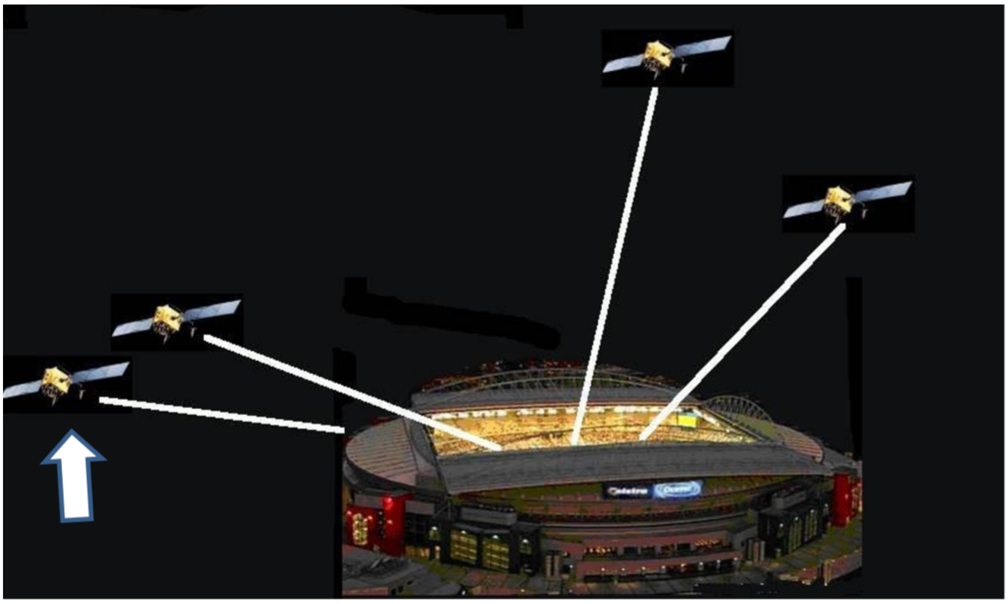

Figure 2.3. Demonstrating the effect of mask angle from a perspective of a modern, large stadium. The white arrow indicates a satellite affected by mask angle**.**
Taken from (Hewitt, 2014).

GPS devices can differ in their internal engine model design. The majority of current devices vary between an internal engine set at 5, 10 or 15 Hz. It has been demonstrated that GPS devices designed at a sampling rate of 10 Hz are 2 to 3 times more reliable than 5 Hz devices when reviewing velocity-based movements (CV = 3.1 to 11.3%) and 6 times more reliable for instant velocity measurements (CV = 1.9 to 6.0%) (Varley, Fairweather and Aughey, 2012). This suggests that measurement is more precise with an increased sample rate. However, when comparing 10 and 15 Hz devices, 10 Hz were more precise (Johnston *et al*., 2014; Malone *et al*., 2017). As a result, the majority of recently released devices are set at 10 Hz. Acceleration is normally analysed at over 0.2 or 0.3 s *via* 10 Hz devices and obtained *via* Doppler-shift (Malone *et al*., 2017). Acceleration is defined as the rate of change of velocity across time (acceleration = velocity/time) which is described as m/s^2, or multiples of g-force with the equation being $1 g = 9.8 m/s^2$ (force of gravity) (Chen and Bassett, 2005). Velocity and acceleration data can be smoothed *via* filtering techniques dependent on the device's manufacturer (Malone *et al*., 2017).

Integration of inertial measurement units consisting of tri-axial accelerometers, gyroscopes and magnetometers have also been introduced, normally sampling at 100 Hz (Malone *et al*., 2017). Accelerometers (motion sensors) measure accelerations from three separate axis (X: front to back), (Y: left to right), (Z: up and down) enabling measurement of aspects such as force and impact. Gyroscopes measure angular velocity and movements and magnetometers magnetic fields and alignment (Aminian and Najafi, 2004; Malone *et al*., 2017). As such micro-movements, velocities and directions irrespective of the devices 's alignment can be analysed.

Within elite football the most prevalent internal load monitoring measures include Heart rate (HR) and rate of perceived exertion (RPE) (Akubat and Van Winckel, 2014). HR could provide a reliable measure of aerobic exercise intensity and has an approximately linear relationship with VO_2 when these measures are recorded over different sub-maximal exercise intensities (Astrand and Rodahl, 1986; Foster *et al*., 2001). Different HR transmitter belt models are available for field-based testing which vary in technology, functional design and cost. Whilst a number have demonstrated validity, there are known issues regarding their use such as cost of HR telemetric systems, displacement during activity and technical failure (Foster *et al*., 2001).

First used by Banister (Banister *et al*., 1975), training impulse (TRIMP) (time, intensity and relative weighting of exercise intensity) provides a single digit measure of TL (exercise "dose") calculated from the heart rate and how long exercise is undertaken in minutes within 'weighted' zones. Subsequently, researchers developed different ways of establishing TRIMP. Edwards (1993) calculated TRIMP TL over five zones and Lucia's TRIMP around three zones (low, moderate and high) (Lucia *et al*., 2003); but the zone weighting has not been validated in either case with any physiological response. These and other earlier methods (e.g., Banister, 1991) were later modified by replacement of the zones with a physiological measurement of blood lactate response.

Originally designed for endurance rather than an intermittent sport such as football, Banister's TRIMP has two important short-comings: mean HR may not reflect the notable fluctuations consistent with intermittent exercise and no consideration is made for differences between individual athletes that might affect the calculation of TL as suggested by model proposed by Impellizzeri *et al*., (2005) as discussed by Akubat and Van Winckel, (2014).

Individualised (i)TRIMP can be calculated from the individual's own heart rate–blood lactate profile in response to exercise and has been validated within elite level football (Manzi *et al*., 2009; Akubat, Barrett and Abt, 2014). Calculation of iTRIMP scores was refined so that a zone was created for each HR reading encompassing HRrest to HRmax (Stolen *et al*., 2005; Ascensao *et al*., 2008). Thus, the limitations of previous models (Banister *et al*., 1975; Banister, 1991; Edwards, 1993; Lucia *et al*., 2003) were avoided, namely weighting according to sex or group and lack of physiological references (Akubat and Van Winckel, 2014; Impellizzeri *et al*., 2005; Stagno *et al*., 2007).

To further improve the accuracy of TL measurements to determine fitness in individual football players, consideration needs to be taken of variable levels of training, match-play and fatigue. It has been suggested that calculation of an integrated external: internal load ratio may be useful and valid in this context when iTRIMP is combined with measurements of total distance covered and high intensity distance in intermittent sport (Akubat *et al*., 2014). Therefore, the routine use of GPS systems to measure external load combined with iTRIMP have allowed for better determination of external: internal ratios within youth footballers (Akubat *et al*., 2018). These relationships were assessed in a small cohort of 10 players and the authors concluded that caution should be taken when using external: internal TL ratios to measure fitness; but that changes in ratios such as total distance: iTRIMP may be useful in determining fatigue, although the small cohort size suggests further investigations are needed. Such a tool might avoid the current problems associated with fatigue and time constraints, the frequency of the actual testing process and the need for players to show their maximum capacity (Akubat *et al*., 2018).

Borg RPE is a numerical rating of physical intensity based on how hard an individual feels they are exerting themselves (Borg, 1990; Akubat, 2012). Measurement is simple, cost and time effective. Different category ratio (CR)-scales have been used to assess perceived exertion. The original version was 6-20 which was then modified to category (C) ratio (R) scale, denoted as Borg CR10 scale (Borg, 1990). All scales have been validated in field-based research, including the most recent a CR100 scale (0-100), though CR10 is used most frequently having the smallest variation of sub scales (Naidu *et al*., 2019). Both CR10 and CR100 scales for RPE were shown to be interchangeable (r = 0.97) in a cohort of elite youth footballers (n = 25, 18.0 ± 0.5 years) (Clemente, Rabbani and Araújo, 2019).

The session-RPE (sRPE) method considers both intensity (through a modified RPE CR10 scale) and duration of training to calculate TL as an arbitrary unit (Foster *et al*., 2001). Investigations with elite youth footballers have identified strengths and weakness of sRPE. For example, sRPE assessed TL intensity better than RPE alone and showed significant relationships between GPS variables in a study of 18 academy players (Marynowicz *et al*., 2020). In contrast, Brink and colleagues found that sRPE did not fit dose-response models (Brink *et al*., 2010), although within a cohort of senior AFL players (n = 46, 22.2 ± 2.9 years) sRPE identified injury risk. Injury risk increased significantly when recorded sRPE scores increased between successive weeks over an entire single season (Rogalski *et al*., 2013). Since elite youth footballers may not be monitored over multiple sessions (including conditioning or technical sessions (on/off pitch)) by load measures such as GPS, the use of RPE values could provide a more complete insight into injury risk when observing load responses (Bowen *et al*., 2017).

Internal load measures were determined by sRPE in the absence of external measures to predict non-contact injury risk within elite Spanish youth footballers (n = 22, 18.6 ± 0.6 years). However, no associations were found between a prediction of noncontact injury occurrence with either weekly load or acute: chronic load (Raya-González *et al*., 2019). Therefore, whilst cost-effective, RPE still requires further evaluation in elite youth footballers to determine its effectiveness in predicting injury risk. Sample size and the number of injuries which occur will be influential in determining successful predictions in these examinations.

In addition to validity and reliability, financial cost and the time needed to process data are important considerations when deciding on which internal load measures to implement (e.g., Foster *et al*., 2001; Impellizzeri *et al*., 2004). Both are imperative for longitudinal research for SOPS to be maintained over the period of research. However, it could be argued that the importance of determining the validity of methods to identify the selected parameters i.e., dose-response relationships, overrides all other considerations.

2.6 Overview of psychological stressors

Lazarus (1966) defined stress as a stimulus, a response, or an interaction between the two and Kenttä and Hassmén (1998) have defined stress as a stimulus inflicting a negative psychological and biological response. Since stress is a reaction to environmental requirements or pressures, the importance of adaptation is significant. Maintenance of physiological integrity in hostile situations requires proficiency of biological systems that control physiological environments (Zhegunov, 2012). An adaptive strategy, initiates systems which respond as rapid and delayed effectors, and changes behaviour to combat stressor exposures. Stress drives adaptation responses quickly to utilise recruitment of resources and restoration of homeostasis (Chovatiya and Medzhitov, 2014). Stress risk factors in professional football take many forms, including game intensity, lack of sleep, and a short regeneration phase between games; competitive training sessions and matches are linked to high physical and psychological pressures (Nédélec *et al*., 2012).

There is little research on the relationship between psychological stress factors and injury in elite football players, although much of the research conducted has revolved around studies focussed on young elite football players (e.g., Brink *et al*., 2010; Dvorak and Junge, 2000; Junge and Dvorak, 2004; Kucera *et al*., 2005; Le Gall *et al*., 2006). Psychosocial influences such as stressful life events, somatic trait anxiety, mistrust and ineffective stress coping can all contribute to an elevated injury risk in young elite football players (Johnson and Ivarsson, 2011). However, psychological factors are not examined regularly within elite senior and youth football environments through measures to examine injury risk, whereas physiological measures are used regularly as part of weekly monitoring structures (Read *et al*., 2016). Information about elite youth players' psychological wellbeing, fatigue and metabolic stress levels would be useful to help reduce the risk of injury and improve performance (Brink *et al*., 2010; Laux *et al*., 2015; Thorpe *et al*., 2015).

To examine the influence of psychological stressors within a sporting context, various models of stress have been constructed (Kenttä and Hassmén, 1998; Williams and Andersen, 1998). The model of Kenttä and Hassmén, (1998) (Figure 2.4) defines the athletic balance, consisting of physical and psychosocial stress alongside recovery components. Disturbance in the balance of these stress factors has a direct effect on the advancement of local or general overload resulting in overtraining an athlete (Kentta and Hassmén, 1998).

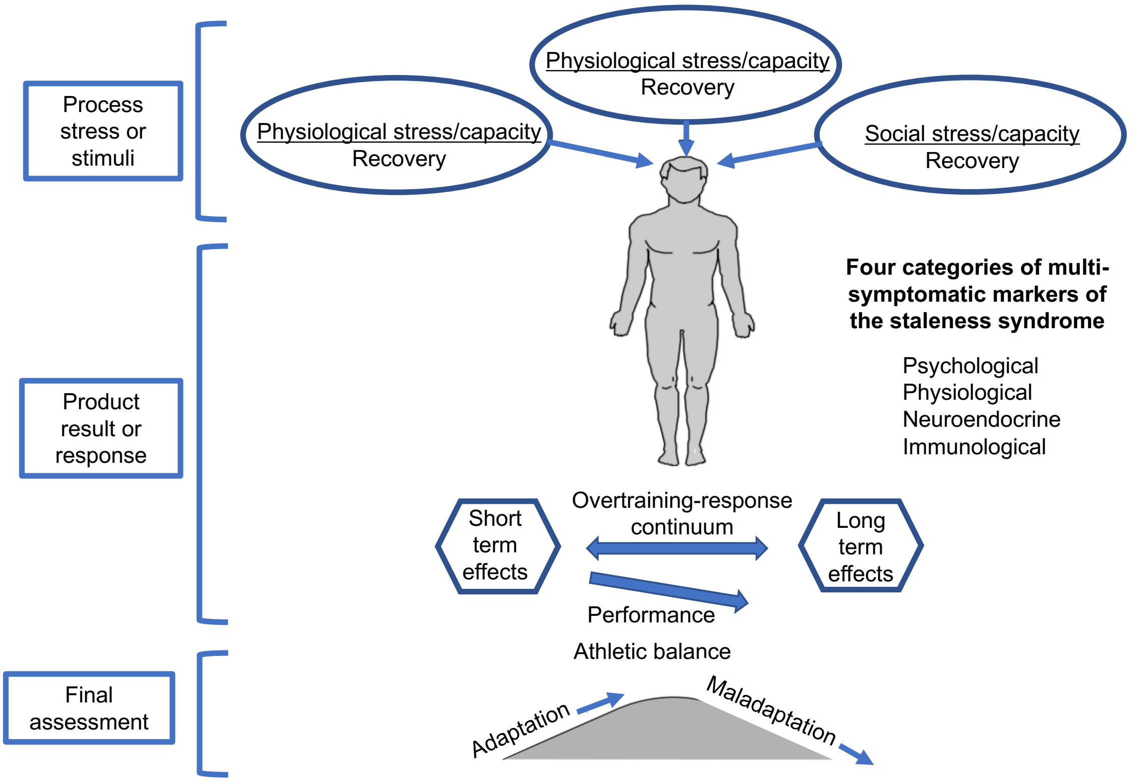

Figure 2.4. Kentta and Hassmén's overview of the whole overtraining and recovery process. Taken from the overtraining and recovery conceptual model (Kentta and Hassmén (1998)).

Williams and Andersen (1998) established the stress injury model, that highlights the interactions of an athlete under stressful conditions (crucial event) with their history of stressors (e.g., major life events and previous injury), personality characteristics (e.g., trait anxiety and perfectionism) and coping resources (social support and psychological skills) (Figure 2.5). The model hypothesises that a history of stressors, personality characteristics (provoking the stress response) and insufficient coping resources will lead to the athlete experiencing heightened stress (varying in intensity) with disruptive physiological activation and attentional deficits, through a bidirectional relationship (Williams and Andersen, 1998). The intensity of a stress response is determined by how threatening the athlete views a situation combined with their subjective ability to handle the situation. Thus, highly perceived threatening situations and low perceived coping skills result in a greater stress response intensity. For example, within a football context a player will use cognitive appraisal of the situation with which they are faced within a training session or a match to consider: "*Can I perform well enough to impress and attain a professional contract*?" Their ability to accomplish those requirements involves their aptitude, and the 'cause and effect' of either accomplishing, or failing, to complete the set task in hand (was a professional contract attained). Stress responses are higher when the player perceives that they do not have the playing ability or physical fitness to fulfil the requirements of that training session or match, which can lead to them assessing the demands as either ego threatening or anxiety-producing (Williams and Andersen, 2007). These same processes can be put into context for a player who is already injured and unable to participate in training sessions and matches, in turn creating the same responses.

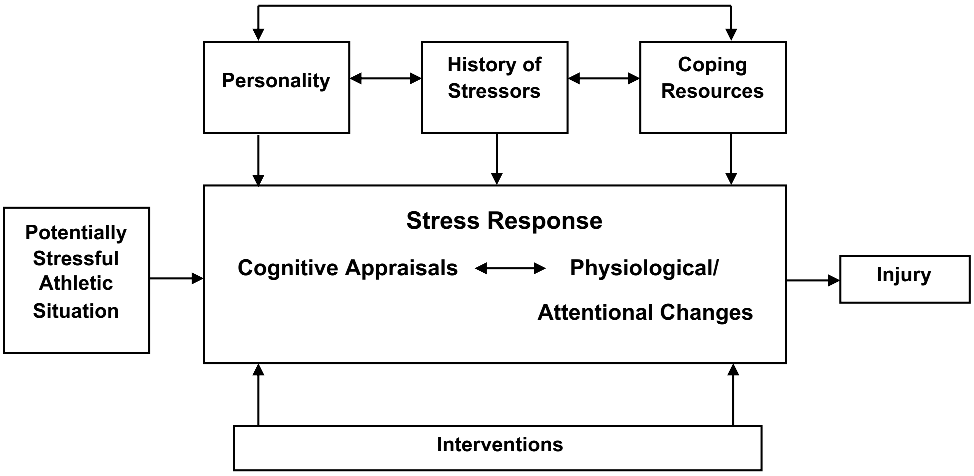

Figure 2.5. Revised version of the stress and injury model. (Taken from Williams and Andersen, 2007).

Attentional and somatic changes (e.g., peripheral narrowing) and changes to physiological and neural functions of the body, such as impacting neuromuscular status with increased rate of fatigue and muscle tension, are determined to be primary outcome effects to stress responses (Andersen and Williams, 1999). The stress reactivity of 'at risk' individuals to an adverse stress response is highlighted as a mechanism for increased injury risk (Williams and Andersen, 1998).

Therefore, the Stress and Injury model (Williams and Andersen, 2007) in combination with the adaption of the dynamic model of aetiology in sports injury (Meeuwisse *et al*., 2007) was used as a framework for the testing design for specific sections of the project.

As an extension of the Williams and Andersen model (1998), it has been hypothesised that an increase in autonomic nervous system (ANS) activation and concomitant behavioural disruptions (e.g., sleep disturbance) can result in a negative outcome such as fatigue or injury. This could be as a result of the demands of intense exercise elevating the risk of injury and illness through the interplay of multiple factors. Stress hormones such as cortisol could extend an individual's exposure to possible illness and injury as a result of high-intensity and high-volume training. Psychological stressors which have a negative effect through extended secretion of catabolic hormones can, in turn, lower immunity and obstruct secretion and enforcement of anabolic functions (e.g., insulin secretion). Training-induced cortisol elevation can create an environment that opens an individual to viral infection, exercise maladaptation and injury (Perna and McDowell, 1995). Links between catabolic hormonal states and impaired immune function and depressed mood have been reported (Barry *et al*., 2020). Identifying negative mood states such as perceived fatigue and depression are used to identify athletes who are overtraining (Gallo, 2016). When performing strenuous physical activity psychological stress has been shown to produce differential effects on neuroendocrine patterns. Individuals exhibited a decrease in cortisol when they had low perceived distress (effort without distress), whereas subjects with high-perceived distress (effort with distress) had an increase in cortisol. Catecholamines were also increased in the latter group (effort with distress) (Frankenhaeuser, 1990). Work by Rimmele and colleagues has determined that male athletes exposed to a psychological stressor, have a significantly lower heart rate and cortisol response in comparison to untrained men. This was accompanied by lower state anxiety and a positive mood. Furthermore, elite sportsmen display a lower reactivity to psychological stress defined by lower adrenocortical, autonomic, and psychological stress responses (Rimmele *et al.*, 2007).

Injury frequencies have been compared against a history of stressors and recovery status within elite youth and senior footballers (Brink *et al*., 2010; Laux *et al*., 2015) and all three of the psychological factors from the model by Williams and Andersen (1998) (history of stressors, personality characteristics and coping resources) have been examined in unison within elite youth and senior footballers (Ivarsson, Johnson and Podlog, 2013; Johnson and Ivarsson, 2011). This thesis has focussed on an examination of the relationships of psychological factors on injury frequencies in elite youth footballers, using previous published research as a template.

2.6.1 Psychological risk factor measures

In house, subjective wellness questionnaires have been constructed to help determine internal stressors within elite youth football (Thorpe *et al*., 2015) and are a popular monitoring tool to observe wellbeing and fluctuations in energy levels and muscle soreness on a daily basis (Adie, Dubie and Ntoumanis, 2012; Coutts, Wallace and

Slattery, 2007; Thorpe *et al.*, 2015). Although the typical wellness questionnaires employed within elite youth football have demonstrated validity and reliability, it could be argued that they cannot examine precisely the main psychological factors highlighted within Williams and Andersen's model of stress and injury (2007) (Figure 2.5). This model of stress and injury comprises various interlinking factors, including personality, history of stressors and coping resources that can influence stress responses singularly, or in combination, and can predict injury occurrence within athletic populations (Ivarsson *et al.*, 2017a and b; Williams and Andersen, 2007).

Validated psychological athlete self-report measures (ASRM) are available to use (Brink *et al.*, 2010) and have been introduced to elite senior and youth footballers to measure stress and recovery levels, some of which tie into the main psychological factors that predict injury occurrence from Williams and Andersen's stress and injury model (1998). ASRM are non-invasive and inexpensive methods of quantifying psychological factors and can be employed within various sporting environments. Specific ASRM can be selected to examine each of the psychological factors identified in the Williams and Andersen model of stress and injury (Figure 2.5), specifically personality, history of stressors and coping resources. However, using a holistic approach would be more effective than just examining a single factor to determine psychological impact on injury risk (Williams and Andersen, 1998).

2.6.1.1 Personality measures

Studies that have used a nomothetic approach have supported correlations between personality variables such as, trait anxiety (Lavellée and Flint, 1996), state anxiety (Sibold, Howard and Zizzi, 2011), type A behaviours (Nigorikawa *et al.*, 2003) and stress susceptibility (Johnson and Ivarsson, 2011 and 2017) with injury vulnerability in athletes. Specific personality traits such as trait anxiety are speculated to enhance the probability of an athlete perceiving a situation as threatening (Ivarsson, Johnson and Podlog, 2013; Perna *et al*., 1998). Consequently, this would have greater effects on physiological stress responses leading to greater injury risk. One component of personality theory that has not yet been considered as relating to sporting injuries is the Reinforcement Sensitivity Theory (RST) (McNaughton and Gray, 2000). The RST is designed to examine the neuropsychological regulation of behaviour and individual variations within neuropsychological systems (Corr, 2004). The RST centres around perceptions of central states of emotion and motivation that can facilitate the relationship between stimulus input and a behavioural response (Corr, 2004). Initially introduced by Gray (1982), the RST encompasses two components, behavioural activation (BAS) and behavioural inhibition system (BIS). Both components were initially introduced to review approach behaviour for appetitive stimuli and avoidance from aversive stimuli (Reuter *et al*., 2015). Gray's model of RST underwent changes by incorporating a third component, the Fight Flight Freeze System (FFFS) (McNaughton and Corr, 2004), producing a revised version of the RST (rRST) (McNaughton and Gray, 2000). This model is unique in a sporting context, as an examination of the rRST model's relationship with sporting injury has yet to be conducted.

Each component of the rRST relates to a particular stimulus. The BAS is predicted to relate to rewarding and appetitive stimuli, such as success from competition whereas FFFS is predicted to relate to punishing and threatening stimuli, for example physical pain from activity. BIS is predicted to relate to goal conflict and can be activated once a threatening stimulus becomes apparent and must be approached, i.e., conflict between approach (BAS) and threat (FFFS). Conflict can also arise when two appetitive stimuli compete for example, choosing between two job offers (Corr, 2008). BIS has an influence on the processes by which anxiety can start and is associated with increased apprehension when faced with potential negative outcome and possible punishments, which are linked to anxiety (Corr, 2008). Numerous questionnaires are designed to measure rRST: Jackson 5, (Jackson, 2009); Reinforcement Sensitivity Questionnaire (RSQ) (Smederevac *et al.*, 2014); Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) (Torrubia *et al.*, 2001); Reuter and Montag's rRST-Q, (Reuter *et al.*, 2015). However, the construct validity of these questionnaires has been questioned with hypothetical and operating limitations being highlighted (Corr, 2016). Corr and Cooper (2016) created the Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ), which has demonstrated sound validity against other personality questionnaires (Corr and Cooper, 2016). The RST-PQ is comprised of 65 statements that measure three major systems: the FFFS, the BIS and four aspects of the BAS. Example statements are provided to illustrate these points: FFFS (10 items) (e.g., *"I am the sort of person who easily freezes-up when scared"*); BIS (23 items) (e.g., *"When trying to make a decision, I find myself constantly chewing it over"*), and four BAS factors (32 items); Reward Interest (e.g., *"I regularly try new activities just to see if I enjoy them"*), Goal Drive Persistence (e.g., *"I am very persistent in achieving my goals"*), Reward Reactivity (e.g., *"I get a special thrill when I am praised for something I've done well"*) and Impulsivity (e.g., *"I find myself doing things on the spur of the moment"*). An additional separate scale, Defensive fight (DF) (8 items) is also included. DF is a specifically separated FFFS associated fight component, related to BAS, though not with FFFS and BIS scales. Items are answered using a 4-point Likert-type scale (1 = *Not at all*, to 4 = *Highly*). Validation of the RST-PQ (Convergent and discriminant) has been described against a previously validated personality questionnaire. Corr and Cooper (2016) utilised an exploratory factor analysis and a confirmatory factor analysis to examine the validity of the RST-PQ. A robust six-factor model diplayed differences between all the RST-PQ factors (Corr and Cooper, 2016).

2.6.1.2 History of stressors

Using psychological measures that determine the impact of stress on recovery states, would be a useful measure to include within sporting environments (Kentta, Hassmén and Raglin, 2006). Whilst limited, some research has examined the links between stress and injuries within elite youth footballers (e.g., Brink *et al*., 2010; Brink *et al*., 2012; Dvorak and Junge, 2000; Junge *et al*., 2004; Kucera *et al*., 2005; Le Gall *et al*., 2006; Price *et al*., 2004).

The influence on injury risk of the psychological factor, history of stressors from the Williams and Andersen model (2007), has been examined and demonstrated that major negative life-events are frequently associated with injury occurrence in athletes (Gunnoe *et al*., 2001; Ivarsson *et al*., 2017a and b; Ivarsson and Johnson, 2010; Maddison and Prapavessis, 2005; Nigorikawa *et al*., 2003; Passer and Seese, 1983; Rogers and Landers, 2005; Steffen, Pensgaard and Bahr, 2009; Williams and Andersen, 2007). Cumulative stressors, such as daily hassles, have had less support regarding their impact on injury (Fawkner, McMurrary and Summers, 1999). It has been suggested that this reflects methodological weakness centred around the inability to record daily hassles effectively (Williams and Andersen, 2007). When observing elite youth footballers over a 10-week period, high preliminary levels of negative daily hassles are associated with higher injury risks (Edvardsson, Ivarsson and Johnson, 2012).

Various ASRM have been developed to measure the impact of stress within athletic populations, including the Athletic Life Experience Survey (ALES) (Passer and Seese, 1983), which records events over the previous 12 months, and is separated into stress subscales such as relationships and an open-ended category. The Life Event Survey for Collegiate Athletes (LESCA; Petrie, 1992) measures possible life events to which participants could have been exposed. Although the LESCA is widely reported within the sports injury literature as a measure of life stress, ethically the LESCA could be unsuitable for young athletes under the age of consent due to the nature of some of the items.

One aspect of the history of stressors that has not been explored in the injury literature is recovery status. For the stress-state to remain consistent increased recovery is required when stress is increased (Kellmann, 2002). This is demonstrated in the scissors model of the interrelation of stress-states and recovery demands (Kallus and Kellmann, 2000). Monitoring of recovery stress-states is necessary to prevent overtraining and maintain peak performance (Kellmann, 2010). Long term imbalance of stress and recovery can lead either to a state of overtraining or injury occurrence if stress is high (Lehmann *et al*., 1999), or an under achievement in performance if a greater amount of recovery is required (Kallus and Kellmann, 2000). Strategies are available to help determine whether athletes are recovering effectively between training and competition (Kellmann and Kallus, 2001), such as examining internal load response changes of daily endurance training sessions (Kellman and Gunther, 2000). Some available ASRM measures allow for stress and recovery states to be monitored, and two examples within sporting environments include The Profile of Mood States (POMS, McNair, Lorr and Doppleman, 1971; McNair, Wood and Marshall, 1992) and The Recovery Stress Questionnaire (RESTQ-Sport), (Kallus and Kellman, 1995). The POMS measures mood and effects from six different states (Tension, Depression, Anger, Vigour, Fatigue and Confusion) using 65 items. POMS does not show details about the causes of overtraining, is lengthy, but is effective in identifying mood fluctuations and monitoring mood subcomponent (Kellmann, 2010). However, the suitability of POMS for athletes is questionable, as it was designed for a clinical population. The RESTQ-Sport was designed specifically for athletes (Kallus and Kellman, 1995). The questionnaire gives an indication of the degree to which athletes are physically and mentally under stress. The

RESTQ-Sport has demonstrated effectiveness within elite youth football to monitor recovery and help to prevent injury and illness (Brink *et al*., 2010). In its earliest form, the RESTQ-Sport contained a very large number of items until three versions were developed, which differed in the number of items (Kellmann and Kallus, 2001; Kallus and Kellmann, 2016). The RESTQ-Sport has received some criticism relating to its factorial structure (Davis, Orzech and Keelan, 2007). A shorter version, the RESTQ-Sport-52 has been highlighted as more suitable for repeated use (Nicolas *et al*., 2019) and has been recommended for longitudinal research (Kellmann and Kallus, 2001). There are benefits to the introduction of the RESTQ-Sport-52 for academy players since it contains a smaller number of items thereby reducing the time taken to complete the questionnaire and allowing for greater concentration on the test. Items are answered using a seven-point Likert-type scale anchored by descriptors ranging from 0 ("*Never*") to 6 ("*Always*"). The 52 items were separated into 19 sub-scales, 7 General stress subscales: General stress, Emotional stress, Social stress, Conflicts/ Pressure, Fatigue, Lack of energy and Somatic complaints; 3 Sport specific stress scales: Disturbed breaks, Burnout/ emotional exhaustion and Fitness/ injury; 5 General recovery scales: Success, Social relaxation, Social relaxation, General well-being and Sleep quality and 4 Sport specific recovery: Fitness/ being in shape, Burnout/ personal accomplishment, Self-efficacy and Self-regulation.

2.6.1.3 Coping resources

The final psychological factor in the Williams and Andersen model is coping resources, highlighting the importance of an athlete's coping ability to combat stressful situations (Williams and Andersen, 2007). An athlete's vulnerability to injury is considered to be heavily related to their inability to cope with major and minor stressors and reduced coping resources have been linked to injury occurences (Johnson and

Ivarsson, 2011). One examination of elite youth footballers has shown that players with poor coping skills, such as worry, had significantly higher injury risks (Johnson and Ivarsson, 2011). Deficient coping skills, such as self-blame, behavioural disengagement (Anshel and Sutarso, 2007) and denial (Lane, Hall and Lane, 2004) have also all been demonstrated in sporting contexts to be associated with injury occurrence.

Coping is an extensive concept, with numerous distinctions such as the disparities between situational coping responses and dispositional coping styles (Monzani *et al*., 2015). As such, measures of coping need to cover all of these distinctions. There are several ASRM that quantify coping resources such as the Ways of Coping Questionnaire (Folkman and Lazarus, 1988), the Multidimensional Coping Inventory (Endler and Parker, 1990) the Coping Inventory for Stressful Situations (Endler and Parker, 1994) and the Coping Responses Inventory-Youth (Moos, 1993). Two of the most popular ASRMs used extensively in the sports injury literature are modified versions of the Ways of Coping Checklist (WCC) (Folkman and Lazarus, 1984) and the COPE instrument (Carver, Scheier and Weintraub, 1989).

Research into coping has mostly focused on the identification of the cognitive and behavioural skills athletes can implement to be able to cope with stressors (Dias, Cruz and Fonseca, 2009). The majority of existing measures were created through observation (e.g., Ways of Coping Checklist; Folkman and Lazarus, 1988), resulting in loose scales with reduced validity (Hudek-Knezevicv, Kardum and Vukmirovicv, 1999). Some measures are thought to give only partial insight into the coping resources of young athletes (Kowalski and Crocker, 2001). To help elevate this issue the COPE (Carver, Scheier and Weintraub,1989) was designed using a theoretical approach that based its design around the following models: Lazarus' model of stress (Lazarus and Folkman, 1984) and the model of behavioural self-regulation (Carver and Scheier, 1990). The

COPE instrument has been validated for use in sport (Gould, Eklund and Jackson, 1993; Gould, Finch and Jackson, 1993; Hardy, Jones and Gould, 1996). One issue is that the COPE contains a high number of items, 60 in total, which could be problematic in the current research programme due to time and participant engagement. The Brief COPE is an abbreviated 28 item version developed by Carver (1997) from the original COPE questionnaire. It measures those coping strategies from the COPE that individuals would be most likely to use in response to stressors. Items are answered using a 4-point Likert-type scale ranging from 1 (“*I have not used this at all”*) to 4 (“*I have used it a lot”*). The 28 items within the questionnaire are separated into 14 subscales: Self-distraction, Active coping, Denial, Substance use, Use of emotional support, Use of instrumental support, Behavioural disengagement, Venting, Positive reframing, Planning, Humour, Acceptance, Religion and Self-blame, which are summed accordingly. The Brief COPE compares well to the full-length COPE inventory, offering good internal consistency, and a valid and reliable tool for assessing stress (Carver, 1997), and has been recommended for use within a sporting environment (Dias, Krutz and Fonseca, 2012). The Brief COPE has also been applied to measure coping and psychological distress caused by deselection within an elite youth football academy similar to the project’s participant cohort (Blakelock, Chen and Prescott, 2019) and for injury prediction within elite senior footballers (Ivarsson, Johnson and Podlog, 2010). The Brief COPE’s maladaptive coping scales (Denial, substance use, Venting, Self-blaming and Behavioural disengagement) are associated with injury risk within footballers (Ivarsson and Johnson, 2010).

2.7 Summary of literature review

In summary, for an elite youth footballer to progress in playing standard there is a definite requirement for them to be available to gain valuable playing experience in training sessions and matches, to develop their playing skills and improve in their physical development. Progressing as many elite youth footballers as possible has distinct benefits for the organisation that invests in their development. Injury is the most common factor reducing availability for cumulative training sessions and competition which impairs a player's technical, tactical, physical and psychological development. It is important to understand the risk factors associated with non-contact injury occurrence to reduce their occurrence.

The risk factors associated with injury can be separated into intrinsic and extrinsic components and can be monitored to assess physical development and psychological changes. It would be insightful to determine how a player's physical and psychological development is affected by non-contact injury and which physiological and psychological measures might help to determine future injury risk. In Chapter 3 protocol details are specified for the measures applied within the research project.

2.8 Aims and objectives

This research project used an observational exploratory perspective to examine the influence of non-contact injury on footballers in an EPPP academy through the use of multiple physiological (physical) measures in combination with psychological measures. Through the incorporation of multiple measures involving diverse mechanisms, the relationships between their change scores across a season could be observed, independent of injury. Selected measures were used to monitor U16, U18 and U23 age groups from the same category 1 academy, on a longitudinal basis, focussing primarily on players within the U18 age group. These elite male academy footballers are at a critical development stage prior to potentially becoming elite senior footballers. It is envisaged that the results from this project will inform researchers, clinicians, and football academy staff involved in monitoring programmes designed specifically for youth academy footballers. Data from these findings may help in developing future initiatives to assess and alleviate potential injury ‘risks’ and facilitate players’ physical and psychological development. The findings from this project may also have an impact across multiple sporting disciplines.

2.8.1 Specific aims

The specific aims of the thesis were as follows:

Study 1

- To assess HSI impact on physical development and match exposure over a season
- To assess whether pre-season physical variables can predict HSI.
- To examine the relationships between growth and physical fitness development, independent of HSI.

Study 2

- To assess the impact of reduced availability due to non-contact injury on players' physical development and their training and match exposure.
- To identify potential risk factors at pre-season which could lead to reduced availability.
- To examine relationships, independent of injury, between growth and physical fitness development, training and match exposure.

Study 3

- To assess the impact of reduced availability due to non-contact injury on both the players' physical and psychological development.
- To identify potential risk factors at the start of the pre-season and competitive season which could lead to reduced availability.
- To examine, independent of injury, relationships between physical and psychological development.

Chapter 3: Measures

3.0 Measures

The purpose of this research programme was to employ an interdisciplinary approach within the structure of a single EPPP-regulated professional football academy in the United Kingdom (UK). To be effective, the testing batteries and procedures had to be reliable and implemented on a regular basis. It was important to assess specifics such as, how the participants and support staff would respond to the tests, the function and known validity and reliability of each test, the time it took to conduct each individual test effectively (especially within the limited time available) (McCall *et al*., 2016), the day and time within the organisation's football programme in which testing procedures and feedback would be best utilised and, most importantly, whether the test was of benefit to the football programme and the overall design of the project. Concentration, mental and physical fatigue of the participants were also considered. For example, maintaining lengthy periods of concentration are known to lead to 'mental fatigue' characterised by feeling tired and lethargic, leading to poor concentration and inability to 'compute' information and to perform skilled tasks (Amann and Dempsey, 2008). Studies have been conducted that show mental fatigue decreases an individual's tolerance to exercise through their perception of the effort involved rather than the physical discomfort and effort evoked by the musculature, cardiovascular and respiratory systems (e.g., Hargreaves, 2008; Lorist *et al*., 2002). Also, there is a consistent link between central nervous system fatigue and physiological impairments such as, loss of the full range of activation of muscle fibres, variations in synergistic muscle contributions enabling force production, and reduced coordination of motor unit firing (Davis and Walsh, 2010). These factors were controlled for as much as possible by allowing for sufficient recovery in the days before and after tests. Also, careful consideration was given to the timing and the number of measures incorporated within a single testing session.

This chapter explains the protocol followed for each measure used in the research for this thesis with references for reliability and validity. Test-retest reliability is also given for growth and physical fitness measures that had to be completed on repeated weeks within a single battery of other measures or exercises for the project (Tables 3.3, 3.5, 3.6, 3.8 and 3.11). The strength of reliability was considered according to quantitative guidelines (Intraclass correlation (ICC): ≥ 0.90 high; 0.80 to 0.89, moderate; ≤ 0.79 poor (Vincent, 2005) alongside a typical error (TE)% of ≤ 10% was considered to be the level at which measures were deemed reliable (Cormack *et al*., 2008).

With the exception of the psychological measures, the validated physical measures reported in this thesis were used in training schedules in the academy and both coaching staff and the players were already familiar with them. It was not possible to extend the breadth of measures because of training and time constraints. However, the physical measures integrated well with the dynamic model of aetiology in sports injury by Meeuwisse *et al*., (2007) (Figure 2.1) and were combined with novel measures incorporated within the academy which examined the psychological factors from the Williams and Andersen's model of stress and injury (Williams and Andersen, 2007) (Figure 3.5). Following a review of the literature, pilot and familiarisation testing, the measures selected for conducting this research project were considered appropriate and to best highlight intrinsic, extrinsic risk factors resulting in injury occurrence and monitoring of player development (physical and psychological). The discussions below focus on these selected measures while details of any equivalent measures applied previously for elite youth footballers that were not used in the thesis are placed in Appendix 2 for comparison with relevant validation and reliability information.

3.1 Schedule for testing

Various periods within the weekly build-up to matches were used to collect measures for the thesis. Pre-training screening was used to identify multiple intrinsic risk factors for injury. The measures used within a pre-training screening session, to determine a participant's readiness to train prior to pitch-based training sessions, were conducted upon their arrival at the training ground (approximately 8:00 to 9:00 am), and are presented in Testing session 1, Table 3.1. Details for specific testing sessions over selected periods of the season are also given (Testing over selected periods, Table 3.1). All procedural tests were conducted to highlight and review various risk factors which could identify whether the participant had a potential risk of injury, their physical development, psychological changes and their exposure levels. Tests that did not require a software interface were collected and inputted into a Microsoft® Excel 2016 document on a laptop device (Mac Office 365, Microsoft, Redmond, WA, USA). This enabled the battery of tests for the project to be collected effectively within the designated time and also to involve and inform the participants about the testing procedures. Participants completed body mass tests prior to consumption of food and/or drink and physical activity, this helped to ensure the reliability of tests and mitigated against confounding variables. For all testing procedures conducted indoors, room temperature was controlled for as much as possible, to remain consistent (Delahunt *et al*., 2011). Testing that was centred around pitch-based training and matches was collected during, and post activity, to examine each participant's training and match exposure levels (Testing session 1, Table 3.1). Table 3.1 shows the timeline of monitoring measures across the 2017/18 and 2018/19 seasons. These were collected regularly throughout the year, except for during a winter break in the last two weeks of December, the off-season break and any extra mid-week fixtures, or changes in the timetable. There were two main testing sessions per day from Tuesday to Friday, one on a Saturday and other specific testing sessions which were set at certain periods of season. The timing of each measure ensured the best possible monitoring of players and provided for efficient feedback to staff and players. Being able to feedback and explain the measures and their outputs to participants, created understanding, competition within participants and gave them encouragement, whilst testing allowed for greater effectiveness because the participants were consistently engaged. For example, for a CMJ test, a connection of a High-Definition Multimedia Interface cable from a laptop to a television screen, allowed players to visualise their asymmetries prior to jumping and their jump outputs as soon as they had completed all efforts. This enabled them to compare their results with previous trials. For each and every measure used, participants were given a detailed description and had a minimum of one familiarisation trial on a separate occasion prior to testing trials for project testing. Within this period, participants were able to ask questions and any necessary corrections to a participant's technique when performing testing protocols would be made. During each trial which involved maximal exertion, verbal encouragement was given to each participant.

Table 3.1. Overview of typical U18 weekly monitoring measures included within each study of the project. Continued on following page.

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Training Overview	**Athletic Development (Md -5)**	**Strength (Md -4)**	**Resistance (Md -3)**	**Speed (Md -2)**	**Match-Prep (Md -1)**	**Match Day**	**Off**
Upon Arrival ~8.00 am	Subjective questions	Subjective questions	Subjective questions	Subjective questions	Subjective questions		
Testing session 1 Morning screening Upon arrival at training ground: 8.00 to 8.45 am Completed in this sequence (top to bottom)		Body mass RHR Dorsiflexion lunge Sit and reach Adductor strength (*via* sphy)	Body mass RHR Dorsiflexion lunge Sit and reach Adductor strength (*via* sphy)	Body mass RHR Dorsiflexion lunge Sit and reach Adductor strength (*via* sphy)	Body mass RHR Dorsiflexion lunge Sit and reach Adductor strength (*via* sphy)		

Table 3.1. Continued.

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Training Overview	**Athletic Development (Md -5)**	**Strength (Md -4)**	**Resistance (Md -3)**	**Speed (Md -2)**	**Match-Prep (Md -1)**	**Match Day**	**Off**
Testing session 2 Outfield training & match measures ~10.30 am to 12.00 pm		GPS RPE CR10	GPS RPE CR10	GPS RPE CR10	GPS RPE CR10	GPS	
Testing over selected periods Time dependent on best applicable to training times	Adductor, abductor strength & imbalance (*via* GroinBar$^{\text{TM}}$) Eccentric hamstring strength & imbalance Psychology questionnaire	CMJ height 5, 20, 30 m Sprints 505-agility Body stature-standing & seated, body mass CMJ impulse & imbalance	Psychology questionnaire	Psychology questionnaire			

Md, Match day; RHR, Resting heart rate; CMJ, Counter movement jump; sphy, Sphygmomanometer; GPS, Global positioning systems; RPE, Rate of perceived exertion.

3.2 Testing protocols to measure growth

Body mass and standing and seated stature were the growth measures implemented for the project. For accurate data collection of total body mass (kg) and stature (cm), body mass was measured to the nearest 0.1 kg and stature measurements recorded to the nearest 0.1 cm; two measures for standing stature and three for seated stature are considered acceptable (Rodacki *et al*., 2001; Ryan *et al*., 2018). Therefore, to ensure stature scores did not differ from each other by more than 0.2 cm within this project, two measures were taken for standing stature and three for seated stature, and the maximum score of each test was recorded (if it did not differ from the other measurements by more than 0.2 cm). For stature, both standing and seated measures were taken using a stadiometer (Model HR001, Tanita 148, Leicester) and a growth and maturation specific box (anthropometric box) (Perform Better, Warwickshire, UK) of 50 cm in height for seated stature. Protocols for standing stature remained consistent with feet, heels (standing) and posterior spine (standing and seated) fixed against the stadiometer, head position fixed with the chin straight and eyes fixed directly ahead (horizontally). Care was also taken to avoid variations such as head position and the timing when the participant was cued to take a breath, which could have resulted in variations in measurements of approximately 0.5 cm (Cameron, 2004). Once the participant was in the correct position, the sliding horizontal headpiece of the stadiometer was placed on the topmost part of the participant's head. No participants within the project wore coverings over their heads and participants' hair height and thickness were accounted for in measurements. The investigator determined for each measurement that the participants' hair structure did not deviate too significantly from previous recordings. For seated stature, the growth and maturation specific box would be fixed evenly against the base of the stadiometer. The participant would sit on the box, with their posterior (tail bone and spine) fixed against the stadiometer, whilst resting their hands on the anterior of their lower limbs, their lower limbs facing forward round the front of the box. The remaining procedure was conducted in the same manner as standing stature.

Digital weighing scales (Seca^{TM} Heavy Duty Digital Floor Scale, Birmingham, UK) were used to measure body mass, as these scales are calibrated, highly accurate and time efficient. To maintain test reliability and time-efficiency, all clothing (socks, shorts, training shirt), equipment and its positioning, were kept the same at each time of testing. Prior to testing participants would remove their shoes and any extra items in their clothing, or accessories such as watches and jewellery. Checks were made that the equipment was placed on a level floor (determined *via* spirit level) and the scales' base pivots were even in length. During testing participants maintained the same anatomical position (with their hands by their sides) during testing. Keeping these protocols uniform allowed for the measurements to be kept reliable (Massard *et al*., 2019; Stewart *et al*., 2011).

All growth measures used for the project have been validated previously and in addition the collection of stature and body mass have been used for growth measurements in elite youth academy footballers and shown to be reliable (Table 3.2). The reliability of the test data was assessed for the equipment and testing protocols used for the project and demonstrated high reliability for all measures (Table 3.3). For test-retest reliability**,** data was obtained under the same conditions from two paired dates one week apart, within the pre-season phase (comparing n = 20 participants).

Table 3.2. Details of growth measures applied within the research project. Continued on following page.

Measure	**Elite youth football use** **Participants (n); age (yrs), or age group**	**Equipment**	**Software**	**Viewpoint of measure**	**Variables obtained from the measure**	**Validation of measure**	**Reliability of measure**
Body Mass	Ryan *et al.*, 2018 n = 130; 13.8 ± 2.9 yrs	Body mass scale	n/a	Total body mass	Total body mass (kg)	Malina *et al.*, 2007	Buchheit and Mendez-Villanueva, 2013 Comparisons: n = 35; ICC = 1.00 (0.99; 1.00)
Stature	Ryan *et al.*, 2018 n = 130; 13.8 ± 2.9 yrs	Stadiometer	n/a	Total body stature	Total body stature (cm)	Massard *et al.*, 2019 Comparisons: n = 38; Pearson correlation = 1.00 (0.99; 1.00)	Buchheit and Mendez-Villanueva, 2013 Comparisons: n = 35; ICC = 1.00 (0.99; 1.00)

Table 3.2. Continued.

Measure	**Elite youth football use** **Participants (n); age (yrs), or age group**	**Equipment**	**Software**	**Viewpoint of measure**	**Variables obtained from the measure**	**Validation of measure**	**Reliability of measure**
Seated stature	Rommers *et al*., 2019 n = 619; U10 to U15	Stadiometer, growth and maturation box (height 40 cm)	n/a	Upper body stature & lower limb length	Upper body stature & lower limb length (cm)	Massard *et al*., 2019 Comparisons: n = 38; Pearson correlation = 1.00 (0.99; 1.00)	Massard *et al*., 2019 Comparisons: n = 38; ICC = 1.00 (0.99; 1.00)

Reliability and validity are displayed for these measures from previous research. n, number (of participants); yrs, years; U, Under (age group); n/a, not applicable; kg, kilogramme; cm, centimetres; mm, millimetres; ICC, Intraclass correlation.

Table 3.3. Reliability data and descriptive statistics for body mass measurements.

Measure	n	Test 1	Test 2	RDM (95% CL)	TE (95% CL)	ICC (95% CL)	CV % (95% CL)	MDC
Weight (kg)	20	72.2 ± 7.8	72.2 ± 8.3	-0.06 (-0.49 to 0.36)	0.65 (0.49 to 0.95)	0.99 (0.99 to 1)	1.0 (0.7 to 1.4)	4.9
Standing stature (cm)	20	179.5 ± 7.2	179.5 ± 7.2	0.04 (-0.03 to 0.12)	0.11 (0.08 to 0.16)	1 (1 to 1)	0.1 (0 to 0.1)	4.3
Seated stature (cm)	20	146 ± 4.3	146 ± 4.3	-0.01 (-0.09 to 0.07)	0.12 (0.09 to 0.17)	1 (1 to 1)	0.1 (0 to 0.1)	2.6

kg, kilogramme; n, number; RDM, reliability difference mean; TE, typical error; ICC, intraclass correlation; CV, coefficient of variation; MDC, minimal detectable change; CL, confidence limit.

3.3 Testing protocols to measure strength

A number of strength measures were applied within the project including the Nordic hamstring exercise (NHE) *via* fixed load cells (NordBord^{TM} VALD^{TM} Performance, Albion, Queensland, Australia), adductor strength *via* sphygmomanometer at 45^{o} hip flexion (Anierod sphygmomanometer, Sports physio supplies, Killinan, Ireland), adductor and abductor strength *via* externally fixed dynamometry (GroinBar^{TM} VALD Performance, Albion, Queensland, Australia) within a custom-built frame at 60^{o} and 90^{o} hip flexion, and a CMJ *via* dual force platforms (PASCO^{TM} PS-2141, PASCO^{TM}, Roseville, California, USA). The next sections will detail the protocols for these strength measures and their reliability. All the strength measures used for the project have been validated, are reliable and have been applied to monitor elite youth academy footballers previously (Table 3.4).

Table 3.4. Details of strength measures applied within the research project. Continued on following pages.

Measure	Use in youth elite footballers Participants (n); age or age group	Equipment	Software, sample frequency (sf)	Viewpoint of measure	Variables obtained from measure	Validation of measure	Reliability of measure
NHE *via* fixed load cells (NordBord)	Fernandes *et al.*, 2020 n = 64; 10 to 16 yrs	NordBord (VALD Performance, Albion, Queensland, Australia)	Scoreboard, (VALD Performance, Albion, Queensland, Australia); sf: 100 Hz	Eccentric hamstring strength from an NHE	e.g., Mean nordic force (N), nordic force between limbs (%)	Opar *et al.*, 2013	Opar *et al.*, 2013 Comparisons: n = 30; ICC = 0.83 to 0.90
Adductor strength *via* sphy at 45^o hip flexion	O'Brien, Santner and Finch, 2018 n = 58; 14 to 21 yrs	sphy (max reading 300 mmHg)	n/a	Isometric adductor strength from a short lever hip adduction position (at 45 ^{o} hip flexion)	Maximum adductor force (mmHg)	Delahunt *et al.*, 2011; Toohey *et al.*, 2018 Comparisons: n = 32; (Pearson's r = 0.77 to 0.91)	O'Brien, Santner and Finch, 2018 Comparisons: n = 30; ICC = 0.91 (0.67 to 0.96)

Table 3.4. Continued.

Measure	**Use in youth elite footballers** **Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from measure**	**Validation of measure**	**Reliability of measure**
Adductor & abductor strength *via* external fixed dynamometry (GroinBar) at 60° & 90° hip flexion	O'Brien *et al*., 2019 Total n = 67, AFL n = 36, footballers n = 31; 20.1 ± 3.40 yrs	GroinBar and adjustable rig fitted with 4 independent, adjustable custom-made uniaxial load cells (VALD Performance, Albion, Queensland, Australia)	(Scoreboard, VALD Performance, Albion, Queensland, Australia); sf: 50 Hz	Isometric adductor & abductor strength from a short lever hip adduction position (at 60° & 90° hip flexion)	e.g., Mean adductor & abductor force (N), adductor force differences between limbs (%)	O'Brien *et al*., 2019 Comparisons: n = 67; (Spearman's Rank Correlation Coefficient R_s = 0.53 to 0.71)	Ryan *et al*., 2019 Comparisons: n = 18; ICC = 0.94

Table 3.4. Continued.

Measure	Use in youth elite footballers Participants (n); age or age group	Equipment	Software, sample frequency (sf)	Viewpoint of measure	Variables obtained from measure	Validation of measure	Reliability of measure
CMJ *via* dual force platforms	Poulson, 2017 n = 16; 19.8 ± 3.8 yrs	PASCO^{TM} dual force platforms PS-2141 (PASCO^{TM}, Roseville, California, USA)	NMP Force Decks^{TM} (London, UK; VALD Performance, Albion, Queensland, Australia) software; sf: 1,000 Hz	Unilateral neuromuscular lower limb power, concentric & eccentric force.	e.g., Concentric mean force (N), eccentric mean force (N), jump height (cm), peak force (N), concentric mean force asymmetry (%), eccentric mean force asymmetry (%),	Lake *et al.*, 2016 (Reactive strength, force time characteristics) Comparisons: n = 21, (r = 0.99 to 1.00) (Jump height) Comparisons: n = 29, (r = 0.99)	Read *et al.*, 2016; Poulson, 2017; Comparisons: n =16; Cronbach's α = 0.79

CMJ, countermovement jump; NHE, Nordic Hamstring Exercise; n, number (of participants); yrs, years; AFL, Australian football league; n/a, not applicable; sphy**,** Sphygmomanometer; Hz, Hertz; sf, sample frequency; N, Newtons; ICC, Intraclass correlation

3.3.1 Testing protocols to measure hamstring strength

Force data from the NordBord is produced from upwards vertical tension enforced on two ergonomic ankle hooks (one for each limb) which are connected to load cells. Project testing followed previously described protocols within the literature (e.g., Opar *et al*., 2015a and b; Timmins *et al*., 2016a). Participants knelt on the knee pad platform of the equipment with their lower limbs facing ergonomic ankle hooks in a comfortable position and perpendicular position. Their ankles were placed inside the ankle hooks, with the back of the ankle against the hooks and the ankles secured immediately superior to the lateral malleolus (Figure 3.1). The ankle braces and load cells were secured to a pivot, allowing for force (N) to be measured through the long axis of the load cells.

Verbal instructions were given prior to starting on the testing protocol. If the participant felt any discomfort (sharp physical pain) during the test they were to stop resisting immediately. Participants were instructed to control their movement, leaning forward with their chest approaching the ground, engaging their hamstrings *via* the ankles hooks to resist the movement. Participants performed the bilateral NHE with a warm-up set consisting of three submaximal repetitions (reps) (with instruction to perform their movements at approximately 70% of their maximal effort). After a 1 min rest, the participant performed one set of three reps, performed at maximal effort (Opar *et al*., 2013). They declined at the slowest speed they could while maximally resisting the movement, concentrating resistance through the posterior of both limbs, whilst maintaining their trunk and hips in a neutral position (Opar *et al*., 2013). Hands were kept held across the chest and were not used to support their lower limbs in any way (Figures 3.1 and 3.2). Once they were unable to sustain the resistance of the motion, they were able to use their arms to stop movement of their upper body before reaching the floor (Figure 3.3). During each maximal effort participants were given loud verbal encouragement to sustain resistance for as long as possible. Execution of all efforts was monitored by the investigator and trials were excluded if the participant exhibited too much forward hip movement from a neutral position, or if at the start of the movement they were unable to control the decline. A trial was approved when force output achieved a distinct peak (indicative of maximal eccentric strength) followed by a rapid decline in force, shown through force curves on the testing software. During each effort, peak force was transferred to the left and right force transducers sampling at 100 hertz (Hz). After NF and imbalance data had been recorded *via* specifically designed software it was transferred to a cloud-based server and exported to raw data files (VALD Performance, Albion, Queensland, Australia) (e.g., Timmins *et al.*, 2016a and b).

Figure 3.1. Start phase of Nordic hamstring exercise testing using NordBord equipment.

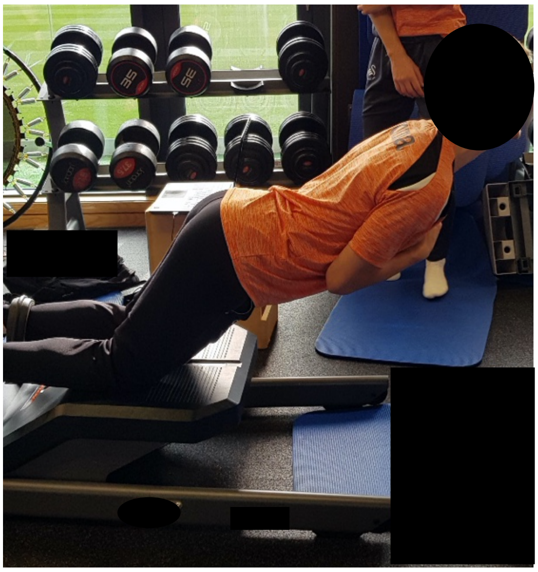

Figure 3.2. Middle phase of Nordic hamstring exercise testing using NordBord equipment.

Figure 3.3. End phase of Nordic hamstring exercise testing using NordBord equipment.

The validity and reliability of NHE *via* the NordBord field testing device has been demonstrated previously. Active males without previous HSI (n = 30) and elite athletes with a previous HSI (within previous 12 months) (n = 20) demonstrated high to moderate reliability (ICC = 0.83 to 0.90; TE = 21.7 to 27.5 N; TE as a coefficient of variation (CV), 5.8 to 8.5 %; MDC at a 95% CI, 60.1 to 76.2 N). In individuals with a previous HSI residual weakness was observed, with the injured limb being 15% weaker compared to the uninjured limb (MD, 50.3 N; 95% CI: 25.7 to 74.9 N; $p < 0.01$) (Opar *et al*., 2013) (Table 3.4). Within the present research project, test reliability was demonstrated for peak NF (N) derived from the NordBord**.** Testing data was obtained with the same testing conditions from two paired testing dates one week apart, within the pre-season phase of Study 1 (comparing n = 14, of 55 participants), with peak and mean force demonstrating high reliability (Table 3.5). The number tested was due to different groups of participants being tested on different weeks during each phase.

Table 3.5. Reliability data and descriptive statistics for Nordic Hamstring Exercise.

Measure	n	Test 1	Test 2	RDM (95% CL)	TE (95% CL)	ICC (95% CL)	CV% (95% CL)	MDC
Nordic force (M of both limbs) (N)	14 (of 55)	337 ± 73	334 ± 64	-3 (-16 to 9)	15 (11 to 24)	0.96 (0.88 to 0.99)	4.7 (3.4 to 7.7)	50
Nordic force (Left limb) (N)	14 (of 55)	337 ± 68	327 ± 63	-10 (-26 to 6)	19 (14 to 31)	0.93 (0.79 to 98)	6.8 (4.9 to 11.1)	48
Nordic force (Right limb) (N)	14 (of 55)	338 ± 84	342 ± 67	4 (-16 to 23)	24 (17 to 38)	0.92 (0.76 to 0.97)	7.7 (5.6 to 12.8)	55

M, mean; N, Newtons; CL, confidence limit; n, number of participants; data given as M and SD of each test, RDM, reliability difference mean; TE, typical error, ICC, intraclass correlation, CV, coefficient of variation; and MDC, minimal detectable change.

3.3.2 Testing protocols to measure adductor and abductor strength

Two protocols were considered appropriate for measuring adductor and abductor strength in the project for the hip and groin, a sphygmomanometer for testing adductor strength and a specifically made dynamometer (GroinBar) for adductor and abductor strength.

Sphygmomanometers are regularly used to measure adductor strength in daily monitoring screenings prior to training and can be used as a tool for both prehabilitation and rehabilitation, through gradual progression in strength adaptations of the adductor muscles (Delahunt *et al.,* 2011). For project testing, the sphygmomanometer was pre-inflated to a suitable level (40 millimetre of mercury (mmHg)) for the participant to apply pressure (Delahunt *et al.,* 2011). It was crucial that this pre-inflated level was kept consistent prior to each measurement. The investigators would ensure that participants adopted a standardised supine position with hips and knees at 45^0 flexion for maximum activity (Delahunt *et al.,* 2011). The participants remained in contact with the floor, did not raise their legs, tilt their pelvis, or lift their heads. Tests were not included if a participant withdrew from the standardised position. The centre of the sphygmomanometer was positioned between the participant's knees, to the most prominent area of the medial femoral condyles (Figure 3.4). Participants would complete isometric adduction for one or more warm-up trials at 70% of their maximum effort, recover, then perform three maximal efforts, from which maximum pressure would be recorded (*via* dial) (Delahunt *et al.,* 2011). When force was applied from adduction of the hips, pressure was recorded at its highest peak level by the investigator (from dial). Further, risks to data integrity of adduction strength tests obtained from a sphygmomanometer are outlined below. Scores for each test were rounded within 5 mmHg to account for potential measurement error, because the dial of the sphygmomanometer was prone to move whilst there was an exertion of maximal pressure and the smaller incremental measurements (within 5 mmHg) on the dial are also more difficult to see within short periods of time (Malliaras *et al.*, 2009). A limitation of using the sphygmomanometer is that it is not designed specifically to measure adductor strength. Damage is common in the form of punctures and displacement of the dial due to pressure applied cumulatively. Therefore, equipment was checked regularly and particularly prior to each testing session. Though measurement of pressure is consistent across models, the diameter of the cuff can differ, which in turn can affect both positioning and ability to exert force; hence, for testing every sphygmomanometer used had the same design.


[redacted]

Figure 3.4. Adductor strength testing performed using sphygmomanometer at 45° flexion of the hip and knee.

The use of a sphygmomanometer for obtaining adductor strength measures has been criticised, despite it being suggested as a valid measure and being regularly used within football environments (O'Brien, Santner and Finch, 2018; Thorborg *et al.*, 2011). A particular concern is that it cannot discriminate between limb differences since only a single measure is obtained from the squeeze motion. There is also a risk of stronger athletes having ceiling effects since typically 300 mmHg is the highest score that can be measured (Thorborg *et al*., 2011). However, the cohort being tested in this project were adolescents, and so ceiling effects associated with higher levels of strength in older players, were less likely to be reached. During pilot (familiarisation) testing, no participants were close to reaching a ceiling effect using the sphygmomanometer, and the test was easily applied on a daily basis within the organisation's weekly schedule. A sphygmomanometer was useful for monitoring adductor strength regularly as groin pain and adductor weakness were both noted commonly within the cohort; but another measure to monitor adductor and abductor strength to a greater accuracy, and the imbalances between limbs, would have been of greater benefit.

Alternatives to sphygmomanometers exist for the measurement of adductor strength that permit multiple muscular skeletal tests to be conducted for individual limbs, thus overcoming the constraints outlined. Tests of the hip and groin, from hand-held (Thorborg *et al*., 2018) and isokinetic (Daneshjoo *et al*., 2013) dynamometry have been implemented within elite youth footballers. However, due to the nature of the protocol for hand-held dynamometry, between-tester bias is a risk (Thorborg, Bandholm and Holmich, 2013).

Isokinetic dynamometry allows measurements to be recorded within a fixed, standardised position and has capabilities for measuring agonist and antagonist variances between muscle groups. However, access to the equipment is limited for most football academies and the test protocol is both time consuming and difficult to implement within practical field-based settings, particularly with numerous athletes being tested at one time (O'Brien *et al*., 2019). A dynamometer specifically made for field-based testing has been developed which allows for abductor and adductor force (N) to be measured between limbs (GroinBar). The GroinBar is easy to apply and can be either handheld or fixed externally to a specifically designed adjustable holding frame (VALD Performance, Albion, Queensland, Australia). The GroinBar is fitted with four independent and adjustable custom-made uniaxial load cells (force transducers).

In this project adductor and abductor strength were examined from 60^{o} and 90^{o} angles for short-lever measurements (requiring flexion of the hips), *via* the GroinBar and the holding frame. Participants would lie with their back evenly against the floor in a supine position with their hips and knees flexed in 60^{o} and 90^{o} positions, resting their ankles on a positioned box so their knees and shins were in line. For adductor strength testing, the medial malleolus of the right leg was then brought in line with the left tibiofemoral joint line followed by the left leg, flexing up so that the medial malleoli were aligned and touching. The force transducers (behind pads) were positioned perpendicular between the participant's knees, so the centre of the pads was at the most prominent point of the medial femoral epicondyles. For abduction testing in the same position of flexion, the lateral femoral epicondyle was aligned with the adjacent force pad.

Isometric contraction protocols for the GroinBar follow those used for a dynamometer. For adduction and abduction testing using the GroinBar, each measure required the participant to squeeze (adduction) or push out (abduction) isometrically for 5 s until peak force was reached separated by a 10 s recovery period (O'Brien *et al.*, 2019). Starting in the 60^{o} position, participants would complete isometric adduction for two sub-maximal practise efforts at 70% of their perceived maximal effort followed by three maximal efforts (O'Brien, Santner and Finch, 2018; O'Brien *et al.*, 2019; Thorborg *et al.,* 2010; Thorborg *et al.,* 2011). Participants would remain in the same position until abductor strength was completed. Tests at 90^{0} would follow, with protocols remaining the same except that the participant had to flex their knees and hips at a 90^{0} start position before performing the test, whilst keeping their hips in a neutral position (O'Brien *et al.*, 2019; Thorborg *et al.,* 2010; Thorborg *et al.,*2011). The order of trials remained consistent through the project. Similar to testing protocols using a sphygmomanometer, obtaining three maximal reps between individuals can be problematic due to the intense nature of the test. If the participant was feeling discomfort after one maximal effort, it was then reviewed whether performing additional maximal efforts would be unsafe. The live feed of data allowed the researcher to evaluate whether maximum force had been reached and therefore the participant could be stopped from overexertion; if discomfort was not verbalised, then this would be clear from the recorded data.

Data derived from the GroinBar were recorded *via* custom made software (Scoreboard, VALD Performance, Albion, Queensland, Australia) compatible with iOS software and matching devices through a USB connection, or a custom-made smart-phone app. The recorded data were streamed live, and force outputs were shown with maximum and average abduction and adduction. The force curves were observed in real time during testing. Force data from force transducers required sampling at 50 Hz and were expressed as absolute values of left and right limbs' peak force (N) and imbalance between limbs (%). Once data was recorded *via* specifically designed software it was transferred to a cloud-based server and exported to raw data files (VALD Performance, Albion, Queensland, Australia) (e.g., O'Brien *et al*., 2019).

The adductor strength test is reliable using either a dynamometer or sphygmomanometer (Toohey *et al.,* 2018) and the test can be performed at various positions of hip and knee flexion for maximum muscular activity (Delahunt *et al.,* 2011; Malliaras *et al*., 2009). Though typically a sphygmomanometer is used to measure blood pressure, it has been validated to measure adductor strength (O'Brien, Santner and Finch, 2018) (Table 3.4). Table 3.6 demonstrates high test-retest reliability within the participant cohort for adductor strength at 45^0 flexion of the hip *via* a sphygmomanometer. To test for reliability, data was obtained under the same conditions on two paired dates, one week apart, within the pre-season phase (comparing n = 20 participants).

Table 3.6. Reliability data and descriptive statistics for adductor strength measurements *via* a pre-inflated sphygmomanometer.

Measure	n	Test 1	Test 2	RDM (95% CL)	TE (95% CL)	ICC (95% CL)	CV% (95% CL)	MDC (95% CL)
Adductor strength at 45^0 degrees flexion of the hip *via* sphy	20	129.3 ± 34.0	128.5 ± 31.8	-0.75 (-6.84 to 5.34)	9.20 (6.99 to 13.43)	0.93 (0.83 to 0.97)	8.2 (6.1 to 12.6)	20

sphy, sphygmomanometer; n, number of participants; data given as M and SD of each test, RDM, reliability difference of the M; TE, typical error, ICC, intraclass correlation, CV, coefficient of variation; and MDC, minimal detectable change. CL, confidence limit.

Test-retest reliability from aligning repeated testing dates and validity for adductor and abductor strength *via* the GroinBar has been demonstrated (CV = 6.3% (4.9 to 9.0%)) within Australian rules footballers and footballers for positions of 60° and 90° flexion of the hip for peak force and rate of force (RFD) development (Desmyttere, Gaudet and Begon, 2019; O'Brien *et al.,* 2019; Ryan *et al*., 2019) (Table 3.4). The GroinBar system has been shown in assessments of adductor strength to have a more efficient measurement accuracy than the use of either hand-held dynamometry or sphygmomanometer. Test-retest reliability from aligning repeated testing dates for hip strength (adduction, abduction, internal and external rotation, flexion and extension) has also been reviewed. This showed that the GroinBar is a reliable tool to assess hip function within footballers (ICC = peak force 0.53 to 0.88; RFD 0.61 to 0.84) (Desmyttere, Gaudet and Begon, 2019).

3.3.3 Testing protocols to measure vertical jump

PASCO^{TM} dual Force Platforms PS-2141 (portable force plates) and compatible software, NMP Force Decks^{TM} software (version (v) 1.2. 6348, London, UK; VALD Performance, Albion, Queensland, Australia) were made available for the project. PASCO Force Platforms (Dimensions: 35 cm x 35 cm; height 0.5 cm; weight, 4 kg; range -1,100 N to +4,400 N) x 2. The platforms are entry level, portable and can be used alone, or in combination. The platforms can be used to measure vertical force obtained during jumping and when used in tandem can measure asymmetries between legs. The single axis model collects data in one plane of motion, the dual axis model collects in two planes, vertical and horizontal. The platforms have the capabilities to collect data *via* a wireless link similar to other VALD Performance based equipment and data can be recorded *via* a USB link and Bluetooth®. The Sparklink Airlink allows for the two PASCO force platforms to run analysis on bi-lateral movements, and for connectivity to be run *via* a cable and Bluetooth. For both methods, the devices' batteries need to be connected to an electronic device, or charged sufficiently prior to connecting to the force plates.

Both the PASCO force plates and the software, which were freely available for use within the project are costly. Though the force plates were acquired through funding, the software was obtained through a founder of the company to assist with data collection for the project. NMP Force Decks software is designed for sporting environments specifically to monitor fatigue, readiness and training and rehabilitation progression, and runs tests *via* dual force plates. The software allows for analysis to be run quickly and within clear visual formats which can be interpreted in real time. Recorded data in turn can be exported to raw data files. Vertical jumps recorded *via* the NMP Force Decks software review multiple variables such as, jump height, asymmetrical differences between limbs (when standing and jumping), RFD development and peak power output. Direct analysis output gives jump height, eccentric power output, concentric power output, and peak power, as well as the average and differences between limbs (%) for all of these variables. These data are used to examine injury risk, performance development and neuromuscular status in athletes (e.g., Claudino *et al*., 2017; Hart *et al*., 2019). The PASCO dual Force Platforms combined with the NMP Force Decks software were deemed appropriate for testing due to the number of variables that could be recorded, including a measure of unilateral differences between limbs *via* dual force plates. Also, the speed and visualisation of data analyses and output for the researcher and the participant cohort make this a valuable analytical resource. Speed of analysis is crucial within sporting environments to allow for all squad members to be tested within short, allocated times for screening. This had the added benefit of keeping the participant cohort engaged and created competition which generated greater buy-in of the participants within the project.

Initially, weekly CMJ jump tests were planned to calculate a player's output (providing an indication of neuromuscular status). The intention was to take the average of three jumps, as a more sensitive measure than the highest jump (Claudino *et al.,* 2017), because individuals are only able to achieve their maximum power/strength in 5% of attempts (Pereira *et al.,* 2014). When average height is used as the final measure the correct probabilities of neuromuscular status are increased to ~50%; with plus one standard deviation, these increased to 68% (Harvill, 1991). However, tests could only be completed on limited dates. Consequently, to determine maximal jump development across the season, the trial with the greatest height (cm) of the three attempts was used for analysis (Ryan *et al*., 2018) with participants cued to aim for the greatest maximal height possible with each jump trial. Some important aspects of analysis had to be considered when using the force plates to ensure accurate recording of data. Due to the nature of data collection *via* the dual force plates, error from jump impact was possible. Therefore, jump efforts with errors within the data output, or force curves within the software, had to be discarded from analysis. Another scenario where tests were not included was when a participant withdrew from the standardised position prior to, and during, jump flight. It was also important to highlight sources of computational error when using software analysis *via* the force-plates. It was necessary to evaluate sampling frequency (sf) and pass filters with cut-off techniques, as the accuracy and measurement of frequency can be affected by underestimations of jump height (Street *et al*., 2001). A low pass off filter with a cut-off frequency of < 580 Hz demonstrated systematic underestimations of jump height. Whereas a low sf (< 1,080 Hz) leads to jump height being underestimated by 4.4% (Street *et al*., 2001). Use of a sf of at least 1,000 Hz is advised for force-time recordings of the CMJ (e.g., Street *et al.*, 2001). Other computational errors include selecting the jump take-off too early (overestimation of $\leq$ 1.5%), the duration of body weight averaging period, gravity constant, the start of integration, the duration of offset averaging period and the sampling duration (< 1% error) (Street *et al.*, 2001). It is important to be able to identify sources of error when measuring impulses within CMJ tests; for example, when measuring variables such as jump height *via* impulse methods (Street *et al.*, 2001). Prior to use, checks were made to ensure that the force plates were placed on a level floor (determined *via* spirit level) set up symmetrically, evenly spaced out (small gap to ensure they were not touching), the pivots at the base of each platform were secure and level in height and loading measurement of the platforms was correct. Soft top mats surrounded the force plates, at the same height, allowing for increased safety and subconscious kinetic motion, giving the participant the room to move away from the platforms if their jump trajectory on descent was not in-line. Participants were instructed to aim for the greatest vertical height for each effort, dipping to their preferred degree (^{0}) of flexion of their knee joints, explode upwards, triple extending at the hip, knee and ankle, and land back to ground, with arms kept akimbo throughout. Away from the platforms participants performed a set of three sub-maximal jumps at 50, 70 and 90% of their perceived maximum effort, separated by a 5 s recovery. Once completed, participants would stand motionless on the platforms for ~3 s to determine standing asymmetrical differences, body mass and the initiation of movement threshold (McMahon *et al.*, 2018). This was followed by completion of three unloaded CMJs with maximum effort (Ryan *et al.*, 2018). Prior to each jump participants were given a ~3 s recovery in which they had to stand as motionless as possible for the force curve to return to an uninterrupted horizontal state. Longer time was taken if issues arose from the software, or if the participant required additional verbal instruction. Tests were not included if a participant withdrew from an akimbo position, if they bent their knees while airborne, or if they did not land on the platforms. If any trials were discarded the participant could have a re-attempt. CMJs were recorded sampling at 1,000 Hz unfiltered, and data analysed *via* the NMP software (e.g., Hart *et al*., 2019; Read *et al*., 2016). Force data was outputted post jump and exported to a Microsoft Excel and PDF format.

Reliability and validity have been demonstrated for CMJs using PASCO portable force plates (recorded at a sample rate of 1,000 Hz) (PASCO 2141) in which the equipment was compared against a validated Kistler force plate (Lake *et al*., 2016) (Table 3.4). Reliability of the single leg CMJ and CMJ vertical jumping *via* dual force plates (PASCO 2141) has also been established within elite youth footballers (Poulson, 2017; Read *et al*., 2016) (Table 3.4).

3.4 Testing protocols to measure flexibility

The sit and reach test *via* a sit and reach box and the dorsiflexion lunge/knee to wall test *via* a tape measure were used in this project due to their previous application in youth football and proven high levels of reliability inside and outside the testing environment (Tables 3.7 and 3.8). Also, the measures could be conducted effectively and quickly within the testing environment and needed only one examiner to oversee and record test results.

Testing equipment and protocols for the dorsiflexion lunge/knee to wall test *via* a tape measure involved setting out a clearly labelled, pre-marked flat scale (cm) against a level wall. No warm-up or mobilisation was permitted prior to starting. Participants (without footwear) faced the wall and aligned their right foot, from the big toe through to the heel, beside the tape on the floor 10 cm from the wall, ensuring their hip and knee were in line and facing towards the wall and that their heel stayed down (flat) on the ground. Whilst keeping their hips in line, participants were instructed to lunge forward, flexing their knee, attempting to touch the wall with their knee. The position of the foot could be adjusted until the knee just touched the wall; the heel remained in contact with the floor throughout. In this position, the ankle joint is in maximal dorsiflexion. The limb not being tested could rest in any position the participant found comfortable and the wall could be held for support. The same protocols were followed with the left foot. Maximum distance from the big toe to the wall for each foot was recorded (cm). Each cm corresponds to approximately 3.6° of ankle dorsiflexion (Konor *et al*., 2012).

A custom made sit and reach box (Perform Better, Warwickshire, UK) (~30.5 cm in height) was required for the sit and reach test. The scale of the box ranges from 0 to 55 cm, it is made from metal and is fixed with secured bolts and is assembled upon delivery. The box needed to be stable and robust enough to perform repeated tests and was examined prior to every use in case of damage or misalignment. The rear side of the box was positioned against a flat surface (wall), to ensure that the box did not move when executing the test. No warm-up or mobilisation was permitted prior to starting. Participants removed their shoes and sat on the floor facing the sit and reach box with straightened lower limbs. They placed the soles of their feet against the box (front side), underneath the scale and their knees were locked in an extended position against the ground with hands on top of one another with palms facing downwards against the scale. Participants reached in a forward motion as far as possible whilst pushing the scale forward and keeping their fingertips against the scale throughout, with hands remaining level, and knees were kept straight. Once at the furthest reach point participants held their position for two s, then relaxed, with their highest reach distance for each trial being recorded (cm). If a participant was unable to reach the 0 cm mark on the box, the score would be marked as 0 cm (Gabbe *et al.,* 2004; Van Doormaal *et al*., 2017).

Highlighting their testing accuracy, the dorsiflexion lunge/knee to wall and sit and reach tests have been validated, their reliability demonstrated, and they have been utilised numerous times within elite sporting environments (e.g., Bennell *et al*., 1998; Gabbe *et al*., 2004)), including within elite youth footballers (Table 3.7). Table 3.8 demonstrates test-retest reliability for both the dorsiflexion lunge test and the sit and reach test used for the project and accounts for the measures being completed within the same testing battery. To test for reliability**,** data were obtained under the same conditions from two paired dates one week apart, within the pre-season phase (comparing n = 20 participants).

Table 3.7. Details of flexibility measures applied within the research project. Continued on following page.

Measure	**Use in youth elite footballers** **Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from the measure**	**Validation of measure**	**Reliability of measure**
Dorsiflexion lunge	Bowen *et al.*, 2019 n = 21; 15.7 ± 0.9 yrs	Tape measure	n/a	Indirect method: Ankle dorsiflexion flexibility	Unilateral ankle dorsiflexion range (cm)	Hall and Docherty (2017). Validity of clinical outcome measures to evaluate ankle ROM during the weight-bearing lunge test. Comparisons: n = 50; r = 0.74 (p = 0.001)	Konor *et al.*, 2012 (Left limb) Comparisons: n = 20; ICC = 0.99 (0.98 to 1.00) (Right limb) Comparisons: n = 20; ICC = 0.98 (0.96 to 0.99)

Table 3.7. Continued.

Measure	**Use in youth elite footballers** **Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from the measure**	**Validation of measure**	**Reliability of measure**
Sit and reach test	Kirkini *et al.*, 2019 n = 103; U15, U17, U19 National team members	Sit and reach test testing box	n/a	Indirect method: Hamstring and lower back extensors flexibility	Sit and reach range (cm)	(Ayala *et al.*, 2012a and b; Lemmink *et al.*, 2003) Reproducibility and criterion-related validity of the sit and reach test and toe touch test for estimating hamstring flexibility in recreationally active young adults. Comparisons: n = 243; (R2 = 0.63)	Gabbe *et al.*, 2004 Comparisons: n = 15; ICC = 0.63 to 0.99

n, number (of participants); ICC, Intraclass correlation.

Table 3.8. Reliability data and descriptive statistics for measurements of dorsiflexion lunge test *via* tape measures and sit and reach test *via* a sit and reach box.

Measure	n	Test 1	Test 2	RDM (95% CL)	TE (95% CL)	ICC 95% CL)	CV % (95% CL)	MDC (95% CL)
Sit and reach	20	26.7 ± 7	26.8 ± 6.9	-0.23 (-1.14 to 0.69)	1.38 (1.05 to 2.02)	0.96 (0.91 to 0.99)	5.8 (4.3 to 8.9)	4.2
Knee to wall (Left limb)	20	11.4 ± 2.4	11.3 ± 2.3	-0.10 (-0.44 to 0.24)	0.51 (0.39 to 0.74)	0.96 (0.90 to 0.98)	5.1 (3.8 to 7.8)	1.4
Knee to wall (Right limb)	20	11.7 ± 2.4	11.5 ± 2.27	-0.2 (-0.8 to 0.4)	0.91 (0.69 to 1.32)	0.89 (0.74 to 0.95)	11.5 (8.5 to 17.8)	1.6

n, number of participants; data given as M and SD of each test, RDM, reliability difference of the M; TE, typical error, ICC, intraclass correlation, CV, coefficient of variation; and MDC, minimal detectable change. CL, confidence limit.

3.5 EPPP fitness testing

To measure physical fitness, the EPPP implemented a specifically designed fitness testing battery for the regular assessment of EPPP academy players (Hulse *et al*., 2013). This includes CMJ, linear sprint speed over 5, 20 and 30 m and the 505-agility test completed in succession within one day (Turner *et al*., 2011). Anthropometric (growth) measures, which include stature and body mass, are usually conducted during this testing battery. Typically, the CMJ, change of direction and sprinting measures are implemented to assess the neuromuscular performance of elite football players. Table 3.9 details designated EPPP physical fitness measures that are used by academies and were applied within the project.

Table 3.9. Details of designated physical fitness measures applied within EPPP academies. Continued on following pages.

Measure	**Use in youth elite footballers** **Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from measure**	**Validation of measure**	**Reliability of measure**
Counter movement jump (CMJ)	Malone *et al.*, 2015a n = 9; 16.4 ± 0.5 yrs	Equipment: Portable photoelectric cell system (Optojump, Microgate, Bolzano, Italy) cell system	software: (Optojump Next v1.7.9, Microgate, Bolzano, Italy), sf: 1,000 Hz	Neuromuscular lower limb power.	Total jump height/ flight time (cm)	Glatthorn *et al.*, 2011 Comparisons: n = 20; ICC = (0.997 to 0.998)	Fitzpatrick *et al.*, 2021 Comparisons: n = 17; Intraclass correlation ICC = 0.88 (0.73 to 0.94)
5 m	Faude *et al.*, 2014 n = 19; 16.5 ± 0.8 yrs	Equipment: Dual-beam electronic timing gates	n/a	Linear sprint speed over 5 m	Sprint time (s)	Rebelo *et al.*, 2013 Comparisons: n = 95; effect size (0.125 to 1.13)	Rebelo *et al.*, 2013 Comparisons: n = 95; ICC = 0.97

Table 3.9. Continued.

Measure	**Use in youth elite footballers** **Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from measure**	**Validation of measure**	**Reliability of measure**
10 m	Buchheit and Mendez-Villanueva, 2013 n = 80; 14.5 ± 1.5 yrs	Equipment: Dual-beam electronic timing gates (Swift Performance Equipment, Lismore, Australia)	n/a	Linear sprint speed over 10 m	Sprint time (s)	Ferro *et al.*, 2014 Comparisons: n = 42; effect size range = 0.23	Jullien *et al.*, 2008 Comparisons: n = 19; ICC = 0.91; CV = 1.8%
20 m	Al Haddad, Simpson and Buchheit, 2015 n = 102; U13 to U17	Equipment: Dual-beam electronic timing gates (Swift Performance Equipment, Lismore, Australia)	n/a	Linear sprint speed over 20 m	Sprint time (s)	Ferro *et al.*, 2014 Comparisons: n = 42; effect size = 0.36	Dugdale, *et al.*, 2019. Comparisons: n = 35; ICC = 0.78 (0.57 to 0.89)

Measure	Use in elite youth footballers Participants (n); age or age group	Equipment	Software, sample frequency (sf)	Viewpoint of measure	Variables obtained from measure	Validation of measure	Reliability of measure
30 m	Al Haddad, Simpson and Buchheit, 2015 n = 102; U13 to U17	Equipment: Dual-beam electronic timing gates (Swift Performance Equipment, Lismore, Australia)	n/a	Linear sprint speed over 30 m	Sprint time (s)	Rebelo *et al*., 2013 Comparisons: n = 95; effect size (0.125 to 1.13)	Rebelo *et al*., 2013 Comparisons: n = 95; ICC = 0.97
505-agility (L and R)	Bianchi *et al*., 2018 n = 21; 17 ± 0.8 yrs	Equipment: Infrared timing gates (Microgate, Bolzano, Italy)	n/a	Linear change of direction speed over 5 by 5 m (10 m total)	Change of direction sprint time (s)	Stewart, Turner and Miller, 2014 Comparisons: n = 44; (r = 0.84 to 0.89)	Kadlubowski *et al*., 2019 Comparisons: n = 27; ICC = 0.72 (0.48 to 0.87)

n, number (of participants); m, metres; L and R, Left and Right; yrs, years; U, under (age group); n/a, not applicable; s, seconds; CV, coefficient of variation; ICC, intraclass correlation, CI, confidence interval.

3.5.1 EPPP fitness testing equipment and protocols

Tests were completed at approximately 9:00 am on a training-based day and players were given ~48 h complete recovery from activity, prior to testing. Finalised results included the best score from each participant of each test. The protocols for each fitness test used by EPPP academies are set and replicated to the EPPP Premier League testing protocol guidelines. Fitness testing data is typically collected at various phases of the season, such as pre-season, start of the competitive season and the end of the season, though this can differ between organisations due to their time constraints, schedule and the availability of participants. The EPPP CMJ test was measured using Optojump (Optojump system^{TM}, Microgate, Bolzano, Italy) previously validated equipment (Glatthorn *et al*., 2011), sampling at 1,000 Hz (measurement accuracy: 0.001 s). An even square was marked out on a level floor with a transmitting and receiving bar (1.0416 cm resolution) placed symmetrically either side. Participants performed a standardised warm-up consisting of a movement syllabus and three unloaded CMJ jumps at 50, 70 and 90% of participant's perceived maximal effort. Followed by three unloaded jumps aiming for maximal vertical height (Ryan *et al*., 2018). Maximal efforts were recorded with the highest jump height (cm) being recorded. Prior to testing, participants were instructed to flex knees to ~90^{o} and keep their hands on their hips for the duration of the movement, land with straight legs and perform a double tap on toes when landing. Any test which did not comply with these instructions was not included in the analysis and participants were allowed another repeat effort. A break of ~3 to 5 s was given between each jump. Verbal encouragement was given to each participant during each test. The highest jump (cm) of the three maximal efforts was recorded for analysis (Ryan *et al*., 2018).

Sprint testing was carried out following CMJ testing and performed on an indoor third generation artificial pitch allowing for consistent standardisation of the ground surface. Sprint distances were measured out by two investigators using a tape measure and coloured cones placed to mark out positions at 0, 5, 20, 30 m points from a starting line. The starting line was 1 m from 0 m giving participants a chance to build momentum prior to the 0 m start. Sprints were recorded using four sets of photocells which were held on tripods 95 cm from the ground paired symmetrically apart at each marker point (Brower Timing Systems^{TM}, Utah, USA). The Brower Timing Systems have been credited with recording short-sprint performance with no systematic bias ($p < 0.05$) (Shalfawi *et al.*, 2012). Participants performed a standardised warm-up including a movement syllabus, building into 3 progressive sprints and one 30 m maximal practise sprint. Prior to testing participants were instructed to adopt a two-point stance at the starting line, with their strongest foot on a line located 1 m behind the 1st photocell, and to run as quickly as possible past the 30 m marked point (Enright *et al.*, 2018). Three maximal sprints were performed, separated by a ~three-minute passive rest (Ryan et al., 2018). The fastest sprint time for each distance to the nearest 0.01 s was recorded for analysis (Stewart *et al.*, 2014). The 505-agility test (Thomas, French and Hayes, 2009) was also applied as part of the fitness testing battery to determine the ability to change direction rapidly (Bloomfield *et al.*, 2007).

Once participants had completed their sprints, they moved on to the 505-agility test. Assessments of change of direction performance were measured using the same photocells placed at the ‘0 m’ and ‘5 m’ (Enright *et al.*, 2018), on the same indoor third generation artificial pitch. Like the sprint tests the start position was 1 m before the 0 m line. Participants were directed to run as fast as they could through the timing gate to the marked ‘5 m’ line with their leading leg touching the line, then to turn and run as quickly as possible back through the timing gates. With each test, the participants were asked to alternate between their left or right foot leading and touching the marked line. The test did not count if the participant failed to touch the marked line with the designated side foot. Each participant completed the test three times on each foot (six in total) with ~3 mins recovery between each attempt. Any attempts which the participant completed inaccurately were repeated at the end. The lowest (fastest) of the three 505-agility sprint times for each foot was recorded (to the nearest 0.01 s) for analysis (Stewart *et al.*, 2014).

Reliability and validity have been demonstrated for all of the fitness tests used within the EPPP physical fitness testing battery for assessing youth footballers (Dugdale *et al.*, 2018) (Table 3.9).

3.6 Testing protocols to measure external load

Although internal load measures were implemented within the project's testing regime, they were not included within analyses due to the design of the studies and procedural complications; only external load measures were included.

Various devices have been designed for both outfield players and GK. In this project a maximum of two GK specific devices (OptimEye G5, Catapult sports, Melbourne, Australia) were used, two within the 2018/19 season and one with the 2017/18 season. Consequently, due to the low number of participants (n = 3 per season) using these devices and performing GK specific movement patterns the variables collected were not utilised for the project's analysis. This is typically the case with numerous studies involving GPS devices measuring load within footballing cohorts, in which there are large differences of total and accumulated velocity speeds between GKs and outfield players, which would leave GKs as an outlier within the participant cohort (Gaudino *et al.*, 2013; Malone *et al.*, 2018). This lack of focus time-motion analyses reviewed for GKs has been highlighted, where it would be ideal to monitor non-locomotive vertical and horizontal actions (Malone *et al.*, 2018). Twenty-eight Catapult

OptimEye X4 GPS devices (Catapult Innovations, Melbourne, Australia) were available for use within the project. The device is ~96 mm in height, ~52 mm width, ~14 mm thickness, weight 66.7 g (per device), accuracy 100 cm. The devices contained a 10 Hz GPS hardware engine, with a tri-axial accelerometer configurable to 100 Hz, 2 to 16 g measuring linear motions, accelerations and decelerations. A 2,000 degrees/s gyroscope configurable to 200 to 2,000 degrees/s measuring angular motion and rotation in order for quantification of specific movement patterns and a magnetometer with axes set at 100 Hz measuring directions and positioning. The device is suitable for monitoring positional and internal movement data and uses Doppler-shift to calculate positional differentiation and velocities (Malone *et al.*, 2017). Multiple variables can be processed from devices with PlayerLoad (PL), total distance (TD) and high speed running (HSR) being commonly used in elite youth football (e.g., Kovács *et al.*, 2020). Time-motion variables such as, HSR are quantified from high intensity speed thresholds which determine the velocity over which distances are covered. Speed thresholds can be pre-set to individual player's speed thresholds for example by using measures of anaerobic threshold, intermittent-exercise capacity and maximum velocity (maximum speed) or in combination. Making speed thresholds on devices relative to individual player's current fitness levels (Malone et al., 2017; Reardon, Tobin and Delahunt, 2015). Alternatively absolute thresholds can be set for specific groups of players i.e., squads, for example (≥ 5.5 m/s) (Suarez-Arrones *et al.*, 2018). Examples and definitions of these metrics are displayed in Table 3.10.

Table 3.10. Global positioning system (GPS) training load variables and operational definition examples

Variables	Operational Definition
Total Distance	Distance covered (m) by all means of locomotion.
High Speed Running	Total distance (m) covered at a velocity > 5.5 m/s (19.8 km/h).
Number of sprint efforts	Count of the number of times a player moved at a velocity > 5.5 m/s for at least 1 s and maintained a velocity greater than 4.4 m/s (15.3 km/h).
Number of acceleration efforts	Count of the number of accelerations, where an individual acceleration is defined as an increase in speed for at least 0.5 s that exceeds a maximum acceleration of 3 m/s.
Number of deceleration efforts	Count of the number of decelerations, where an individual acceleration is defined as an increase in speed for at least 0.5 s that exceeds a maximum acceleration of 3 m/s.
PlayerLoad^{TM}	Sum of g forces in each individual axial planes (anteroposterior PlayerLoad, mediolateral PlayerLoad, and vertical PlayerLoad). PlayerLoad equation: $\text{PlayerLoad} = \frac{\sqrt{(\alpha_{y1} - \alpha_{y-1})^2 + (\alpha_{x1} - \alpha_{x-1})^2 + (\alpha_{z-1})^2}}{100}$ α_y = forward acceleration α_x = sideways acceleration α_z = vertical acceleration
Repeated high intensity efforts	Count the number of times a player performs 3 high intensity efforts (> 14.4 km/h), separated by less than 21 s between each effort.
Maximum Velocity	Maximum velocity (km/h) achieved.

For data collection (during activity) a custom neoprene GPS vest or a shirt with a GPS pouch were required for each participant. Prior to activity, participants were assigned a GPS device (labelled accordingly by number) and wore a specifically fitted GPS vest capable of holding a device in a pouch between the scapulae which would cause no discomfort, have minimal movement or becoming unattached whist taking part in pitch-based training and matches (Lazarus *et al.*, 2017). The assignment of the device and vest helped avoid between-unit error and mitigate errors from movement artefact within the vests (Scott and Lovell, 2018) Each participant was assigned a vest at a size (small, medium, large and extra-large) most appropriate to them prior to the start of a competitive season. If a participant lost their vest prior to activity they were given a spare. The devices were charged sufficiently prior to use using a chargeable carrier case (X4 Charge Case; Catapult Sports, Queensland, Australia). The devices were turned on by pressing the power button until the main light-emitting diode (LED) light flashed green continuously. Devices were turned on a minimum of 15-mins prior to each training session and match, to determine an appropriate satellite network connection (Scott and Lovell, 2018) The devices were then secured in the vest so that the LED light was not concealed. Post activity, each device was turned off and the activity for each individual device was downloaded *via* a custom-made USB cradle, processed retrospectively and filtered accordingly to Catapult's specialised algorithm ('intelligent motion filter'). The algorithm designed by Catapult analyses Doppler-shift velocity and inertial sensor measurements in combination, thus identifying locomotor errors (Scott and Lovell, 2018). Once checked for errors, trimmed and synced to a cloud-based server to access the raw data in a csv format *via* Openfield software (v 1.18.0, Catapult sports, 2018) (e.g., (Scott and Lovell, 2018)).

Validity and reliability have been reported for variables collected from GPS devices used within the project with: total distance (CV = 1.9%), high velocity running (CV = 4.7%), accelerations (CV = 4.9%), and decelerations (CV = 11.3%) (Rampinini *et al.*, 2015; Varley, Fairweather and Aughey, 2012). Within elite Australian footballers, PlayerLoad (Mooney *et al.*, 2013), and inter-unit reliability of accelerometer derived data

(CV = 1.94%) (Boyd, Ball and Aughey, 2011) have been reported to be valid measures of intensity. Reliability and validity of instantaneous velocity during acceleration from 10 Hz GPS devices have been reported (Akenhead *et al*., 2014). Table 3.10 demonstrates the validity, reliability, and examples of use within elite youth footballers for the Catapult designed devices (both satellite based and with an internal accelerometer) which were used within the project. When using GPS devices, factors such as, sample rate, smoothing filters, location, satellite availability and weather can all have significant impacts on the quality of data (Hewitt, 2014; Malone *et al*., 2017) and were taken into consideration when testing.

Table 3.11. Details of external load measures applied within the research project.

Measure	Use in youth elite footballers Participants (n); age or age group	Equipment Software, sample frequency (sf)	Viewpoint of measure	Variables obtained from measure	Validation of measure	Reliability of measure
Monitoring of external load velocities *via* internal tri-axial accelerometer, gyroscope, magnetometer and satellite-based positioning system	Lovell *et al*., 2019a n = 278; U15	GPS device OptimEye X4 (Catapult sports, Melbourne, Australia) Openfield software (Catapult sports, Melbourne, Australia) sf: 10 Hz engine accelerometers/ magnetometers sf: 100 Hz default	Time-motion variables covered within pitch-based training sessions and matches	e.g., Total distance (m), high speed running (m), explosive distance (m), total PlayerLoad (au), number of sprints, sprint distance (m)	Johnston *et al*., 2014; Weaving *et al*., 2017	Johnston *et al*., 2014 Comparisons: n = 8; (p = 0.05) (% TEM = 1.3%)

Measures labelled * were applied within the project. GPS, Global positioning system; n, number (of participants); m, metres; U, under (age group); n/a, not applicable; sf, sample frequency; Hz, Hertz; s, seconds; au, measurement of load; CV, coefficient of variation; ICC, intraclass correlation, CI, confidence interval; and TEM, Typical error of measurement.

3.7 Psychological risk factor measures

The following ASRM were considered the most suitable to be applied within the project for the specific subject cohort to examine each of the psychological factors within Williams and Andersen's model of stress and injury (Williams and Andersen, 1998; Williams and Andersen, 2007).

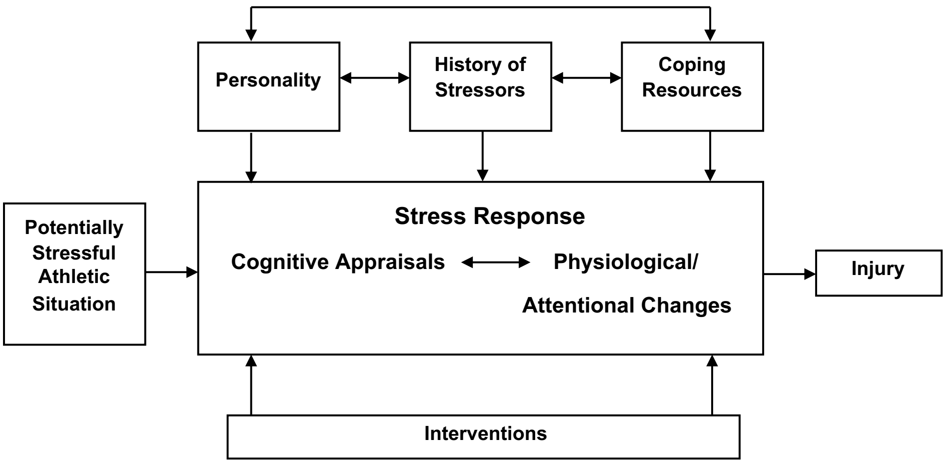

Figure 3.5. Revised version of the stress and injury model. (Taken from Williams and Andersen, 2007).

3.7.1 Personality measures

To examine personality, the RST-PQ was chosen for the project. The RST-PQ has demonstrated reliability previously (FFFS, $\alpha = 0.78$; BIS, $\alpha = 0.93$; BAS, α, 0.74 to 0.86) (Corr and Cooper, 2016). Cronbach's alpha (α) $\geq$ 0.70 are typically interpreted as acceptable (e.g., Kellman and Kallus, 2001). Cronbach's α is one of the most consistently applied tests within psychological-based research. It is used to examine reliability and is considered beneficial when item-specific variance from a unidimensional test is of note (Yang and Green, 2011). However, limitations have been indicated regarding how the size of α is affected by item number, dimensionality and average item intercorrelation. Also, consideration should be taken into account of multi-dimensionality, leading to overestimations of reliability (≥ 0.70) (Yang and Green, 2011). The descriptive statistics and scale correlations from the development and validation of the RST-PQ by Corr and Cooper (2016) are displayed in Appendix 2. The full RST-PQ questionnaire is displayed in Appendix 3.

3.7.2 History of stressors

The RESTQ-Sport-52 questionnaire has been validated (scale criterion, factorial) and demonstrated reliability (e.g., Kellmann and Kallus, 2001; Martinent *et al*., 2014; Tibbert, Morris and Andersen, 2009) and has been used with elite senior and youth footballers (Brink *et al*., 2010; Laux *et al*., 2015). The original procedure for the measure involved repeated administration every three days (Kellmann and Kallus, 2001). The RESTQ-Sport scales have demonstrated high test-retest reliability (α > 0.79) alongside good internal consistency (α, 0.67 to 0.89) (Kellmann, 2010; Kellmann and Kallus, 2001; Laux *et al*., 2015). The measure has an improved internal consistency (α > 0.79 *vs* α > 0.59) for administrations every 24 h compared to α > 0.59 for administrations 3 days between testing intervals (Kallus and Kellmann, 2001). The day-to-day high internal consistency of the RESTQ-Sport has been demonstrated previously within an elite youth football cohort (α, 0.81 to 0.97) (Noon, 2016) (Appendix 2).

The RESTQ-Sport 52 was chosen for the project, although it was unrealistic in this testing environment to apply the ASRM either daily or every three days. This is due to the time pressures affecting the accuracy with which the questionnaire would be completed, and because the weekly structure of the organisation might have resulted in the questionnaire being completed inconsistently across weeks. Completing the questionnaire monthly was more realistic and has been deemed credible within an elite football environment (Laux *et al.*, 2015). Such monthly monitoring is supported by evidence from previous studies where the RESTQ-Sport was completed by professional football players (Brink *et al.*, 2010; Laux *et al.*, 2015). Hence, the measurement was conducted every month, two days prior to the last game of the month, instead of every three days. This was the only measure within the project where a testing protocol was modified. The full RESTQ-Sport-52 questionnaire is displayed in Appendix 3.

3.7.3 Coping resources

The Brief COPE was considered the most suitable measure of coping resources for adoption in this project. Validation of the Brief COPE has been demonstrated with good discriminate and convergent validity (factor structure comparable to COPE) (Carver, 1997); Yusoff, 1994). Also, its reliability has been confirmed within various groups (Cooper, Katona and Livingston, 2008; Muller and Spitz, 2003; Yusoff, Low and Yip, 2010), including athletic populations (Dias, Krutz and Fonseca, 2009). Initial reliability demonstrated for the Brief COPE ranged from α, 0.50 to 0.90 (Carver, 1997), with similar findings within an athletic population (α, 0.48 to 0.82) where six (Substance use, Emotional support; Instrumental support; Behavioural disengagement, Humour and Religion) of the fourteen scales were $\alpha > 0.70$ (Dias, Krutz and Fonseca, 2009) (Appendix 2). Despite reliability not being $\alpha \geq 0.70$ for all of the scales, they were all implemented within the project. This is in keeping with previous research reports with footballers to examine both adaptive and maladaptive aspects of the measure (Ivarsson and Johnson, 2010). The full Brief COPE questionnaire is displayed in Appendix 3.

3.8 Summary

The aim of this chapter was to provide details of the protocol followed for every measure used in the subsequent studies with references for reliability and validity. Factors that were taken into consideration included the repeatability of the measures, whether the measures had been implemented previously within cohorts similar to the current programme (elite youth footballers) and, if not, whether they would still be suitable. Importantly, the measures had to fit within the organisation’s weekly schedule and the staff and players of the organisation had to engage and adhere to them.

Chapter 4: Study 1

An examination of hamstring injury, physical development and match exposure time in elite academy footballers

4.1 Abstract

Objectives. To assess HSI impact on physical development and match exposure over a season and whether pre-season physical variables can predict HSI. To examine the relationships between growth and physical fitness development, independent of HSI.

Design. A longitudinal observational study comparing multiple physical fitness, growth variables and total match exposure time across an EPPP season.

Participants. Footballers (n = 55) (14.1 to 23.0 years; stature 175.3 ± 8.8 cm and body mass, 67.3 ± 10.1 kg) from U21 (n = 13), U18 (n = 17) and U16 (n = 25) squads in a single EPPP category 1 academy.

Main outcome measures. Physical fitness measures (NF, NF imbalance between limbs *via* a NHE, CMJ jump height, 5, 20, 30 m sprints, 505-agility tests) and growth measures (stature and body mass) obtained at pre-season (baseline) and late-season (end of season). HSI data and total match exposure time were collected throughout season.

Results. Participants were categorised into two groups dependent whether they had sustained a HSI across the season. Participants not sustaining a HSI were 2 years younger and had increased NF development over the season when compared to those sustaining a HSI (MD, 47 N, 95%, CI = 3 to 91 N; $p = 0.0378$). An association between baseline NF scores and NF change scores was observed, where greater NF improvements over the season were found in weaker participants. Specifically, those participants who had a pre-season NF of ≥ 365 N (outside the error associated with change in mean force) did not improve NF, regardless of group. Participants who did not sustain a HSI, gained greater body mass compared to those sustaining a HSI (MD, 1.7 kg; 95% CI, 0.1 to 3.3 kg; *p* = 0.0427). Sustaining a HSI had no significant impact on total match exposure time, though a large amount of time was lost. Independent of HSI, increases in CMJ jump height were conducive to improved sprint performance (i.e., 30 m sprint: r = -0.55, large; *p* = 0.0194). Furthermore, some improvements in physical fitness development were a function of increased growth. Examples include: CMJ jump height which increased with stature (r = 0.47, moderate; *p* = 0.0066) and body mass (r = 0.48, moderate; *p* = 0.0050).

Conclusions. A HSI can result in lost match time, impaired NF development and body mass gain, justifying implementation of monitoring measures. A 'ceiling effect' observed when some players reached a specific NF cut-off threshold, could be overcome by adding load when performing an NHE. Longitudinal NF testing could potentially be used to inform specific exercise prescription in those academy footballers identified at risk of impaired NF gains due to HSI, or when they exceed NF over a specific threshold. Development across a season of vertical jumping capabilities could reflect improved sprint speeds and physical fitness development could be influenced by growth development.

4.2 Introduction

'Availability' and an ability to perform are critical to an academy footballer's development; although within regular high-level academy football, there are increased possibilities of injury occurrence (Jones *et al.*, 2019; Price *et al.*, 2004). Time lost due to injury can have a detrimental impact on career progression since opportunities, such as gaining match experience, are lost (Jones *et al.*, 2019). Furthermore, the player's club will have lost an investment. HSI are common in football and occur mostly when running at high speed or sprinting (Duhig *et al.*, 2016; Evans and Williams, 2017). A HSI can occur when an athlete dynamically lengthens their hamstring muscles in an aggressive motion, within the terminal swing phase of sprinting (e.g., Chumanov, Heiderscheit and Thelen, 2011; Schache *et al*., 2009; Thelen *et al*., 2005). However, the mechanism behind the injury is still under debate (e.g., Van Hooren and Bosch, 2017a and b; Kenneally-Dabrowski *et al*., 2019; Kalkhoven *et al*., 2020).

Injury audits of academy footballers have shown the average time loss per injury, is 21.9 days (Read *et al*., 2018b) and an average of 2.31 ± 3.66 matches are missed (Price *et al*., 2004). Furthermore, a recent EPPP audit indicated that HSI accounted for 6.1% of all injuries with 49 occurrences over a season (Read *et al*., 2018b). Across the 2014/15 season, the hamstring anatomical area sustained the highest amount of non-contact injuries (1.5/1,000 h exposure) within a single EPPP academy (17.3 ± 0.9 years). This suggests that HSI in academy footballers, like elite senior footballers, could result in significant absence from competition and training (Ekstrand, Hägglund and Waldén, 2011; Woods *et al*., 2004). Examining the time academy players miss playing experience because of injury is important. Further context is needed with respect to the nature, severity and influence of specific injuries within academy cohorts (Price *et al*., 2004). This is particularly true for injuries such as HSI, which has been shown to be one of the most significantly damaging non-contact injuries, that disrupts academy footballers' playing development time (Read *et al*., 2018b).

To reduce HSI occurrence in academy footballers it is important to understand the risk factors associated with HSI. Based on prior research, HSI occurrence has drawn associations with mutifactoral, inter-relating, risk factors. Insufficient hamstring strength, asymmetrical imbalances of hamstring strength between limbs and previous HSI occurrences have been universally highlighted as the risks predominantly associated with future HSI in adult footballers and Australian Football League (AFL) players (e.g., Arnason *et al*., 2004; Hägglund, Waldén and Ekstrand, 2006; Timmins *et al*., 2016a; Verrall *et al*., 2001). Despite lower limb strength and imbalance being known injury risk factors for academy footballers, there is minimal current research focussing on the associations of HSI with established HSI risk factors, within elite academy football (Read *et al*., 2018a). Identification of the physical measures that could best indicate potential HSI risks during critical development periods, such as a pre-season, would be invaluable for academies in mitgating these risks (e.g., Bourne *et al*., 2020; Noon *et al*., 2015). This is particularly true when the exposure demands on players are elevated (e.g., Ekstrand *et al*., 2019; Read *et al*., 2018a).

Eccentric strength training using the NHE is one method suggested to offset the risk of HSI, potentially through lengthening of the muscle BFLH fascicles and increasing strength of the knee flexors (Opar, Williams and Shield, 2012a and b). The NHE has gained support for reducing HSI incidence and evidence of its success has been demonstrated in a number of large studies (e.g., Arnason *et al*., 2008; Mjølsnes *et al*., 2004) including two randomised control trials (Petersen *et al*., 2011; van der Horst *et al*., 2015). A systematic review and meta-analysis examining the impact of NHE on HSI rates in football players estimated that teams incorporating the NHE within injury prevention programmes decreased HSI rate by 51% longitudinally in comparison to those that continued with regular football training (Al Attar *et al*., 2017). Based on these positive outcomes, and the ease with which the exercise can be performed individually, or with a partner, the NHE has been included as part of injury reduction programmes aimed specifically for footballers (Al Attar *et al*., 2017). Yet, despite the positive findings, barriers exist within some elite football environments to using NHE in its own right, or in a battery of exercises (Bahr, Thorborg and Ekstrand, 2015). The most common barrier to including NHE as part of training for coaches is the anticipated hamstring muscle soreness that players, unaccustomed to performing NHE may experience and a perception that this itself may lead to HSI. Such soreness may remain for up to 72 h post-exercise and can lead to undesired outcomes including, impaired performance in subsequent activities, or restricted training and competition availability (Bahr, Thorborg and Ekstrand, 2015). Two studies, which found no significant association between prescribed NHE protocols and HSI rates, have declared low compliance by players (Engebretsen *et al.*, 2010a; Gabbe, Branson and Bennell, 2006; Gabbe *et al.*, 2006). Also, low compliance to the NHE may be due to the volume of training prescribed and the demand on footballers to play multiple matches with relatively short 'turn-arounds' for recovery. An additional barrier is that the anticipated benefits of NHE may be diluted by exposure to predominantly concentric muscle action conditioning (Woods *et al.*, 2004; Askling *et al.*, 2007; Ekstrand *et al.*, 2012). These barriers require further examination, especially as compliance to prescribed programmes involving NHE, notably in-season, are sometimes infrequent. Obtaining evidence for the benefits of applying the NHE as a method to monitor strength levels of academy footballers, could help reduce these possible barriers in academy football.

While positive outcomes from the inclusion of the NHE in physical preparation plans have been reported, evidence pertaining to the 'dose' required is lacking and it is unclear what level of stimulus (i.e., volume and intensity) is required for positive changes in footballers to continue long-term. Comparable eccentric strength and architectural adaptations were achieved in active males using either a high or low volume eccentric NHE training programme spanning six weeks (two weeks of standardised practise, then four weeks of either high or low volume) (Presland *et al.*, 2017). The authors suggested that when HSI preventative programmes are designed to facilitate BFLH fascicle length, appropriate execution and intensity of eccentric exercise may be the priority, rather than application of a higher training volume (Presland *et al*., 2017). Therefore, achieving the appropriate level of training volume and not exceeding this would be more effective for the football environment.

Measurement of NF obtained during the performance of NHE, can help to identify those athletes at risk of future HSI (Opar *et al*., 2014; Timmins *et al*., 2016a) and highlight whether any strength improvements have been achieved. However, developing an academy footballer's athletic performance involves improving a multitude of aspects all considered important in reducing injury risk (Reilly *et al*., 2000; Lloyd *et al*., 2016). By implementing systematic fitness assessments throughout a football season, coaches can determine players' responses to the stimuli to which they are being exposed and whether they are improving physiologically (Reilly, 2006). Category 1 EPPP academies adopt the Premier League fitness testing battery including the CMJ, linear sprint speed over 5, 20 and 30 m and the 505-agility test. Growth (anthropometric) measures are conducted during this testing battery which includes stature and body mass. These tests are completed in one day (Turner *et al*., 2011) and have been assessed regularly in football players (Hulse *et al*., 2013). Observing growth and physical fitness development across a season is crucial to determine whether elite academy footballers are improving physically. Furthermore, observation of the relationships between various measures could suggest how growth and physical fitness might affect one another (Hammami *et al*., 2013). Additionally, if physical measures are completed at baseline points, observations of these measures can be explored against future injury rates to ascertain whether alterations can be identified to predict potential injury risk (Noon *et al*., 2015; Read *et al*., 2018a).

To date, there have been no reports of the specific impact of HSI on changes in physical fitness and match experience in an EPPP football academy over a football season. The main purpose of this study was to describe the impact of HSI occurrence on changes in physical fitness and growth measurements in EPPP academy football players from the start to the end of a season and on total match exposure time for the entire season. Other aims included the examination of differences in scores of multiple physiological measures (growth, physical fitness) taken at pre-season in relation to HSI occurrence and finally, the observation of relationships between growth and physical fitness development, independent of HSI. It was anticipated that findings could provide academy football coaches and practitioners with information on specific monitoring observations that they could make across a competitive season, to improve player's physical development and reduce HSI rates.

4.3 Methods

4.3.1 Participants

All participants were male elite academy football players from the same category 1 EPPP Premier League academy. The 84 participants first involved with the testing procedure had a minimum of one NHE assessment to measure NF. Participants were from U16 (n = 30), U18 (n = 21) and U21 (n = 33) age group squads and aged from 14.1 to 23.0 years, with stature 176.7 ± 8 cm and body mass 69.2 ± 9.9 kg. Of these participants, 55 were included within the analysis: U16 (n = 25), U18 (n = 17) and U21 (n = 13) age group squads, aged from 14.1 to 23.0 years, stature 175.3 ± 8.8 cm and body mass 67.3 ± 10.1 kg. All participants were contracted to the club on a full-time scholarship and/or had a professional contract and were medically cleared to play at the start of the season on the basis of cardiac and medical screening by the club. The specific criteria outlined below determined the inclusion criteria of participants. All participants, where age appropriate, provided written consent or assent, and their parents or guardians provided written consent prior to the start of testing. Ethical approval for the study was obtained from the University of Wales Trinity Saint David Ethics Committee (ethics code: EC162) prior to all testing procedures.

4.3.2 Inclusion criteria

All participants were required to be full time players within the U16, U18 and U21 age group squads during the 2015/16 EPPP season. Participants were included who remained injury free, had completed at least one NHE assessment within both the pre-season and the end of season and had their match exposure time recorded across the season. Participants who sustained a HSI had to have completed a minimum of one NHE assessment within either the pre-season or the end of the season, if their HSI prevented them from completing any assessments. Participants could not be included without a complete record of their HSI history.

4.3.3 Design and procedure

For this longitudinal observational study, all testing sessions took place at the same training ground. The study spanned 12 months from the start of pre-season until the end of the competitive 2015/16 EPPP season and academy year (June 2015 - July 2016). For analysis purposes, the testing was divided into two phases, which were pre-season (baseline) (June 2015 - September 2015) and late season (end of season) (April 2016 - July 2016). NHE testing comprised of a total of ten testing sessions, five sessions within each of these two phases (Table 4.1). NHE testing sessions were conducted alongside the participants' athletic development sessions and were used as the participant's NHE exercise for the session. Physical fitness and growth testing comprised of two sessions, one session within each phase (pre- and late season) (Figure 4.1). Each participant's age was recorded at the start of the testing (pre-season), playing position and match exposure time were recorded at the end of the season. Injury data for the participants were analysed prior to the start of each testing session and any participant with a previous history of HSI was highlighted. Participants were reviewed by the team's medical staff to determine if they were fit and available for any testing procedures at the designated times. Participants who had sustained any injury, or were rehabilitating during the testing period, were only able to continue with the study if cleared to do so by the medical staff. For all testing procedures, if the participants' scores indicated an issue or they indicated verbal discomfort prior, during, or after, they were directed to the medical staff at the organisation and were reviewed to determine the appropriate treatment. All participants were familiar with, and had completed, all of the testing procedures before the study commenced.

Table 4.1. Nordic hamstring exercise testing dates according to phase in the season.

Phase	**Pre-season**	**Late-season**
Testing Date	21/08/15	13/04/2016
	26/08/15	27/04/2016
	10/09/15	05/04/2016
	16/09/15	12/05/2016
	30/09/15	17/06/2016

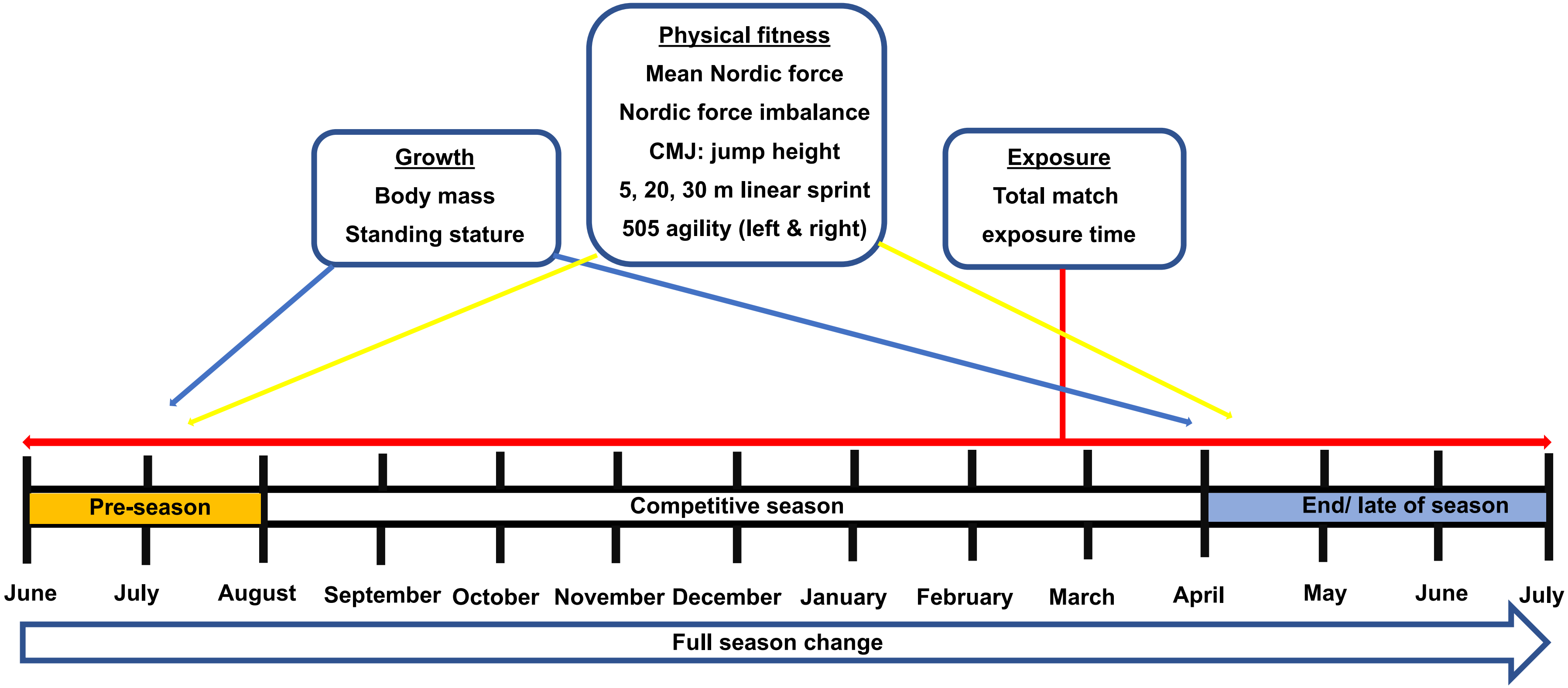

Figure 4.1. Timeline of physical and match exposure measures included within the study. CMJ, counter movement jump. Thick white arrows show the period over which change scores were calculated across the season. Coloured arrows (yellow, red and blue) indicate the time point at which growth, physical fitness and match exposure time measures were collected.

4.3.4 Nordic hamstring exercise training volume

Each participant completed one gym-based conditioning session including two sets of 3 to 6 reps per week of the NHE prior to, and during, the testing period. Each session also included normal posterior chain exercises with one knee bend and one hip bend (three sets of 3 to 6 reps for each) per week, unless a player was carrying a related injury, which prevented them from executing the movement. This volume was prescribed according to published literature (e.g., Presland *et al*., 2017; Opar *et al*., 2015a and b; Timmins *et al*., 2016a). Sessions were completed every training week of the season. Sessions were completed on either the first or third day of each training week (5 or 3 days prior to the designated match day), according to the physical development programme of the academy.

4.3.5 Participant details

Participant details comprised age, playing position and playing squad. Age was recorded in years, playing position recorded as the participants' most predominant playing position through the testing period. Positions were identified as: GK, Fullback (FB), CB, Centre midfield (CM), Winger (WG), Striker (ST). Players were separated into U16, U18, U21 playing squads.

4.3.6 Injury details

Participants' HSI occurrences prior to, and during the testing period, were obtained through the organisation's injury database (PMA, The Sports Office, UK). Due to the recognised influence of previous HSI on HSI reoccurrence, previous HSI was recorded for the 12 months before the start of the testing period (Timmins *et al*., 2016a). All injury details and definitions included in this study were the same as those that had to be recorded by EPPP academies, as required by the Premier League. These details were also replicated in a recent injury audit of EPPP academies (Read *et al*., 2018b). All injury details and descriptions within the database were diagnosed and recorded by the club's medical staff. Thereafter, the information was reviewed for each participant and exported to raw data files. HSI details included the type of injury, which limb was injured (left *versus* right), the muscle injured (BFLH, BFSH), semimembranosus, semitendinosus), the injury location (proximal or distal, muscle belly or muscle-tendon junction), injury grade (0, I, II, III) (Pollock *et al*., 2014), the time and phase of the season (pre, early, mid, late) of injury occurrence and return to play. Only injury data related to HSI soft-tissue (non-contact) injuries were exported and analysed. No other type of injury or HSI impact injury was examined.

HSI was defined for this study as the participant having a diagnosed HSI by a member of the medical team at the organisation. The criteria used for this diagnosis are that the player is suffering from pain and damage in the posterior thigh (hamstring) in either the muscles and/or tendons, and that this has resulted in a cessation of exercise involving movement and engagement of that muscle group within football-based activity, not including any impact injuries. The number of matches missed was defined as matches for which a participant was not available for selection due to a HSI. Time lost due to HSI was specified by the number of days that elapsed from the day following injury occurrence to the date on which the player returned to training, as confirmed by the medical staff. HSI recurrence rate was determined by the number of repeated HSI injuries for the season (e.g., Read *et al*., 2018b; Timmins *et al*., 2016a).

4.3.7 Growth and physical fitness measures

Growth and physical fitness data (with the exception of NF measures obtained by external investigators) were obtained from the organisation's personal performance database. Data was inputted into the data base immediately post-testing by the club's fitness coaches. All data for each participant was reviewed and exported. Physical fitness data included: CMJ, 5, 20, 30 m sprints and 505-agility tests. All protocols for each fitness test were set and replicated to the EPPP Premier League fitness testing protocols and were implemented by the fitness coaches from the academy and the Premier League. For full details and reliability of testing procedures see Chapter 3.

4.3.7.1 Growth. Anthropometric (growth) data included: body mass and stature. Body mass (kg) was measured on Seca digital floor scales (Seca Heavy Duty Digital Floor Scale, Birmingham, UK) and stature (cm) *via* a stadiometer (Model HR001, Tanita 148, Leicester).

4.3.7.2 Vertical jump height. Participants performed three unloaded CMJ jumps (Ryan *et al*., 2018) aiming for maximal height, with trials recorded *via* Optojump (Optojump-Next system, Microgate, Bolzano, Italy) (Glatthorn *et al*., 2011). Participants were instructed to flex knees, explode upwards, triple extending at the hip, knee and ankle whilst keeping arms akimbo for the duration of the movement, land with straight legs and perform a double tap on toes when landing. Of the three maximal efforts, the highest jump (cm) was recorded for analysis (Ryan *et al*., 2018).

4.3.7.3 Linear sprint performance. Sprint testing was carried out following CMJ testing and was conducted on an indoor third generation artificial pitch, with times measured using four pairs of photocells (Brower Timing Systems, Utah, USA) (Enright *et al*., 2018). Three maximal sprints were performed, separated by a ~three-minute passive rest (Ryan et al., 2018). The fastest sprint time (s) for each distance was recorded for analysis (Stewart, Turner and Miller, 2014).

4.3.7.4 Change of direction. 505-agility testing was carried out following CMJ testing on the same indoor third generation artificial pitch, with times measured using two pairs of photocells (Brower Timing Systems, Utah, USA) (Enright *et al*., 2018). Each participant completed the test three times each, on each foot (six tests in total), separated by a ~three-minute passive rest. The fastest of the three 505-agility test times (s) for each foot (left and right) was recorded for analysis (Stewart, Turner and Miller, 2014).

4.3.7.5 Eccentric knee flexor strength. The Nordbord field testing device (VALD Performance, Albion, Queensland, Australia), was used to assess NF *via* the NHE (Opar *et al*., 2013). Following previously described protocols (e.g., Opar *et al*., 2015a and b; Timmins *et al*., 2016a), participants knelt on the device with their ankles secured immediately superior to the lateral malleolus *via* separate ankle hooks. They performed one set of three reps at maximal effort. During trials, peak force was transferred to the L and R force transducers sampling at 100 Hz. Data analysis for NF was calculated *via* Peak NF (N) for each limb (left and right) with mean force of both limbs determined (N). NF limb imbalance between limbs was calculated as a percentage difference (%) (Timmins *et al*., 2016a). For each participant, the trial with the highest mean NF produced within each phase was used for analysis. This minimised the effect on maximal scores from any muscle soreness and fatigue (Chapter 3) that participants would develop within the season.

4.3.8 Total match exposure time

Exposure data was obtained from the organisation's player match records, on the Premier League's database (PMA) (The Sports Office, UK). The total amount of match time each player attained was inputted into the PMA immediately post-match by performance-analysis staff, after being calculated from the match analysis report and video analysis. The total exposure time of match play for each participant was reviewed and exported to raw data files for further analysis. Total match exposure time was defined as the total summed time (mins) accumulated during matches in which the player participated across the testing period.

4.4 Statistical analyses

Statistical analysis was completed using JMP v 15.0 Pro Statistical Discovery Software (SAS Institute, Inc, Cart, North Carolina USA). Descriptive statistics were reported for all variables. Data are displayed as the (mean (M) ± standard deviation (SD)), or (mean difference (MD), 95% CI, probability value (*p*)) or (correlation coefficient (r); *p* (if significant)), unless indicated otherwise. Significance was set at a confidence of 0.95 ($p < 0.05$) and where possible Cohen's *d* (effect size) was reported for comparisons, the magnitude of the effect was interpreted as small, < 0.2; medium 0.5; and large 0.8 (Cohen, 1988).

$$d = \frac{|m_1 - m_2|}{\sqrt{\frac{(n_1\text{-}1)s_1^2 + (n_2\text{-}1)s_2^2}{n_1+n_2\text{-}2}}}$$

Equation for Cohen's *d* (effect size) accounting for unequal *n*.

Where appropriate, Shapiro-Wilk test was used to examine variables for normal distribution. A log transformation was performed on variables which were not normally distributed. Levene's test was used to examine equality of variance (homoscedasticity) between HSI injury groups. A flow-chart outlining the statistical analysis is displayed within Appendix 2.

To examine the impact of previous HSI on re-injury, a contingency analysis was performed. Just for this contingency analysis, participants were separated into four groups: Group1: No previous HSI prior to the study's data collection (No previous HSI)/ No injury within the study testing period (No HSI); Group 2: Previous HSI/No HSI; Group 3: No previous HSI/HSI; Group 4: Previous HSI/HSI. Any HSI that a participant had sustained within the past 12 months prior to the beginning of testing was described as 'Previous HSI' (Timmins *et al*., 2016a). Any HSI sustained during the testing period was described as 'HSI'. By running the contingency analysis, any significant influence of previous HSI could be determined in the present cohort who sustained a HSI within the testing period. The analysis used a likelihood ratio and reviewed the RR of HSI occurrence within the testing period against a previous HSI. From a comparison of these groups the risk of previous HSI occurrence would be determined if only Group 4's RR score was higher than 1. RR denotes the ratio of the probability of injury occurring in the previously injured group compared to the probability of injury occurring in the previously uninjured group (Schmidt and Kohlmann, 2008).

Participants were grouped according to whether they had sustained a HSI within the testing period or not. Group categorisation: 1- No HSI injury within the testing period and 2- HSI injury within the testing period.

Age was calculated by years from the day of birth to the first day of the pre-season (testing period). To calculate change scores across the season for physical fitness and growth measures, each participant's end of season score was subtracted from their pre-season (baseline) score. From the physical fitness measures, improvements would show a positive score with exceptions of NF imbalance (%) the 5, 20 and 30 m sprints (s) and 505-agility, where a negative score would reflect an improvement.

Due to the exploratory nature of the study, univariate analyses were completed involving multiple independent *t*-tests. The impact of HSI occurrence (HSI groups) was compared against age, total match exposure time, all the baseline and change scores across the season for measures of physical fitness and growth. Each individual *t*-test compared the two HSI injury groups for each of the variables separately. Since the study was exploratory in nature, Bonferonni corrections were not performed to account for multiple comparisons. Mean values for the HSI group were subtracted from those for the no HSI group to obtain the MD.

Multiple independent Pairwise correlations were performed to examine the associations between the change scores across the season, for measures of physical fitness and growth, with each measure being paired against one another. The Pairwise correlation analysis allowed for the change scores (physical development) to be observed independent of HSI occurrence within a data set which included a large number of physical variables. For Pairwise correlations (r) the following conditions were followed to examine the strength of correlations: r, < 0.1 trivial; r, 0.1 to 0.3 small; r, 0.3 to 0.5 moderate; r, 0.5 to 0.7 large; r, 0.7 to 0.9 very large; r, 0.9 to 1.0 almost perfect (Hopkins, 2000), alongside their significance ($p < 0.05$). Based on previous research within similar cohorts, considerations were given to the strength of the associations from the final Pairwise correlations (e.g., Comfort *et al.*, 2014; Malone *et al.*, 2015a).

4.5 Results

Stature development was the only variable that was not normally distributed, although following a log transformation of the data the variable passed the Shapiro-Wilk test for normality ($p = 0.1253$). All variables demonstrated equality of variance between the two HSI groups ($p > 0.05$).

4.5.1 Previous hamstring strain injury review

Eight of the fifty-five participants sustained a previous HSI, from which six remained injury free, while two went on to sustain another HSI during the season. Of the remaining forty-seven who had no history of HSI, seven went on to sustain a HSI, while forty were HSI free. Previous HSI was not associated with subsequent HSI within the testing period (likelihood $\chi 2$ (df = 1) = 0.463, p = 0.4960), (RR = 1.7; 95% CI, 0.4 to 7.1). The number of players who had previously sustained a HSI, who either went on to sustain a HSI within the testing period or not, are shown in Table 4.2.

Table 4.2. Examination of hamstring strain injury reoccurrence.

	No HSI within testing period	HSI within testing period	Totals
No previous	40	7	47
Previous HSI	6	2	8
Totals	46	9	55

HSI, hamstring strain injury.

4.5.2 Injury details

Nine of the fifty-five participants sustained a HSI injury within the testing period. HSI from each squad were as follows U21, n = 5; U18, n = 3 and U16, n = 1, and playing position was: FB, n = 1; CB, n = 1; CM, n = 2; WG, n = 3; ST, n = 2. A total of eleven HSI were recorded (4 left-leg and 7 right-leg), two of which occurred during pre-season, one in early season, five in mid-season and three in late-season. The breakdown of the injury incidence according to squad was: U21, n = 8; U18, n = 2; U16, n = 1. One participant had two HSI injures in the same limb and two participants had two HSI injuries, one in both limbs. Four HSI were semi-membranous/ tendinosis strain and seven were strains of the biceps femoris strain. The HSI ranged in severity: two, grade 0; six, grade I; and three, grade III. The number of days within the testing period when players were injured (due to HSI) and unable to participate in training sessions and matches was recorded as a median of 10 (range, 1 to 33 days), and the number of matches missed as a median of 1 (range, 0 to 5 matches).

4.5.3 Impact of hamstring strain injury

Baseline growth and physical fitness measures demonstrated no group differences. However, the majority of participants not sustaining a HSI were younger (MD, -2.1 years; 95% CI, -3.6 to 0.7 years; p = 0.0053). Table 4.3 describes baseline differences with respect to HSI across growth and physical measures and details of the participants as determined by multiple independent *t*-tests.

Table 4.3. Baseline differences of participant details, growth and physical measures with respect to hamstring strain injury.

Variables	No HSI	HSI	Mean difference	95% Confidence Interval	*p*- value [1]	Effect size (Cohen's *d*)
Age (years)	16.2 ± 1.9 (n = 46)	18.3 ± 2.5 (n = 9)	-2.1 ± 0.7	-3.6 to 0.7	0.0053**	1.1
Body mass (kg)	66.8 ± 10.2 (n = 35)	70.8 ± 10.6 (n = 5)	-4.1 ± 4.9	-14.0 to 5.8	0.4110	0.4
Stature (cm)	175.1 ± 9.1 (n = 35)	177.0 ± 7.7 (n = 5)	-2.0 ± 4.3	-10.6 to 6.7	0.6481	0.2
Mean Nordic force (N)	342 ± 70 (n = 46)	381 ± 68 (n = 7)	-40 ± 28	-96 to 18	0.1712	0.6
Nordic force imbalance (between limbs) (%)	8.8 ± 6.3 (n = 46)	12.4 ± 9.9 (n = 7)	-3.6 ± 2.7	-9.0 to 2.0	0.1907	0.5
CMJ jump height (cm)	34.6 ± 5.0 (n = 36)	37.8 ± 7.0 (n = 5)	-3.2 ± 2.5	-8.2 to 1.8	0.2050	0.6
5 m sprint (s)	1.00 ± 0.06 (n = 38)	0.99 ± 0.06 (n = 5)	0.01 ± 0.03	-0.04 to 0.07	0.6022	0.2
20 m sprint (s)	3.03 ± 0.14 (n = 38)	2.94 ± 0.13 (n = 5)	0.09 ± 0.07	-0.05 to 0.22	0.2036	0.7
30 m sprint (s)	4.32 ± 0.20 (n = 25)	4.17 ± 0.13 (n = 5)	0.15 ± 0.14	-0.14 to 0.45	0.2886	0.8
505-agility right (s)	2.51 ± 0.08 (n = 34)	2.49 ± 0.11 (n = 5)	0.03 ± 0.05	-0.07 to 0.12	0.5735	0.2
505-agility left (s)	2.52 ± 0.07 (n = 34)	2.46 ± 0.10 (n = 5)	0.07 ± 0.04	-0.01 to 0.15	0.1031	0.8

[1] All significant *p*-values are labelled accordingly: $^{**}p < 0.01$; years, years; CMJ, counter movement jump; HSI, hamstring strain injury.

By the end of the season, those who had not sustained a HSI injury had increased NF development (MD, 47 N; 95% CI, 3 to 91 N; *p* = 0.0378) compared to those who did sustain a HSI (Table 4.3). The two participants suffering the greatest reduction in NF across the season both sustained two HSI during the season (drop in NF separately: -91 N and -39 N) (Figure 4.2). From a predictive expression (cut off) of both non-injured and injured groups, those who had a NF score ≥ 365 N (outside the error associated with change in mean force) did not improve in NF over the course of the season (*p* = 0.001) (Figure 4.2). Participants not sustaining a HSI demonstrated a greater increase in body mass across the season than those sustaining a HSI (MD, 1.7 kg; 95% CI, 0.1 to 3.3 kg; *p* = 0.0427). HSI impact was not shown within any of the other change scores recorded across the season for physical fitness or growth measures. No differences were found between HSI and non-HSI participants in total match exposure time (mins) across the season (MD, 409 minutes (mins); 95% CI -158 to 977 mins; *p* = 0.1541). Table 4.4 describes the change scores and match exposure time across a season in relation to HSI, from multiple *t*-tests.

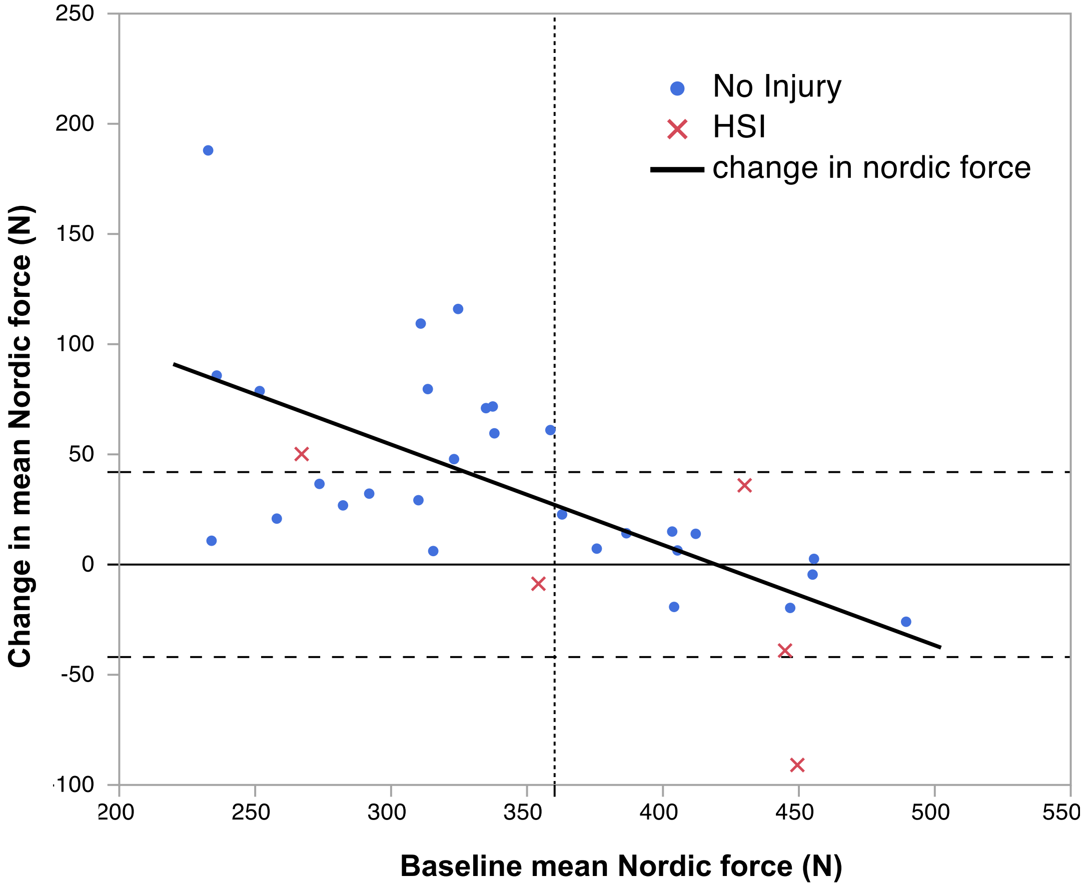

Figure 4.2. Change in mean Nordic force across a season between hamstring strain injury groups, including a predictive expression (cut off). Blue dots represent non HSI participants, red crosses represent HSI participants, the thicker black line is a line of best fit representing the change in Nordic force (N). Baseline of change in mean force is set at 0 N with positive (higher; horizontal dashed line above 0 N) and negative (lower; horizontal dashed line below 0 N) scores from 0 N representing an improvement or reduction, respectively. Predictive expression (cut off) was set at 365 N (vertical dotted line) demonstrating that participants, regardless of HSI group, did not improve in Nordic force outside the error associated with change in mean force.

Table 4.4. Differences in match exposure time, growth and physical fitness development with respect to hamstring strain injury.

Variables	No HSI	HSI	Mean difference	95% Confidence Interval	*p*- value [1]	Effect size (Cohen's *d*)
Body mass (kg)	2.2 ± 1.7 (n = 27)	0.5 ± 0.9 (n = 5)	1.7 ± 0.8	0.1 to 3.3	0.0427*	1.1
Stature (cm) §	0.0 ± 0.4 (n = 27)	0.1 ± 0.1 (n = 5)	-0.1 ± 0.2	-0.4 to 0.3	0.6127	0.3
Mean Nordic force (N)	36 ± 46 (n = 46)	-11 ± 57 (n = 5)	47 ± 22	3 to 91	0.0378*	1.0
Nordic force imbalance (between limbs) (%)	0.3 ± 8.5 (n = 46)	1.6 ± 15.8 (n = 5)	-1.3 ± 4.4	-10.2 to 7.5	0.7624	0.1
CMJ jump height (cm)	1.3 ± 2.2 (n = 29)	0.9 ± 1.8 (n = 5)	0.4 ± 1.1	-1.8 to 2.5	0.7380	0.2
5 m sprint (s)	-0.02 ± 0.06 (n = 29)	-0.02 ± 0.04 (n = 5)	0.00 ± 0.03	-0.05 to 0.05	0.8446	0.0
20 m sprint (s)	-0.06 ± 0.09 (n = 29)	-0.07 ± 0.06 (n = 5)	0.01 ± 0.04	-0.08 to 0.09	0.8578	0.1
30 m sprint (s)	-0.08 ± 0.13 (n = 16)	-0.02 ± 0.07 (n = 5)	-0.06 ± 0.09	-0.26 to 0.14	0.5273	0.5
505-agility right (s)	-0.09 ± 0.09 (n = 25)	-0.10 ± 0.07 (n = 5)	0.01 ± 0.05	-0.09 to 0.11	0.9262	0.9
505-agility left (s)	-0.08 ± 0.08 (n = 25)	-0.03 ± 0.10 (n = 5)	-0.06 ± 0.05	-0.15 to 0.04	0.2332	0.7
Total match time (mins)	1914 ±791 (n = 46)	1505 ± 689 (n = 9)	409 ± 283	-158 to 977	0.1541	0.5

[1] All significant *p*-values are labelled accordingly: *< 0.05; CMJ, counter movement jump; HSI, Hamstring injury; § log transformed.

4.5.4 Correlations of change scores

Means and SDs for baseline and development variables independent of whether participants sustained a HSI (Table 4.5). Participants' change scores were utilised for correlational analysis.

Table 4.5. Baseline and development scores independent of hamstring strain injury. CMJ, counter movement jump; § log transformed.

Variables	Baseline (pre-season) scores	Development (Change) scores
Body mass (kg)	67.3 ± 10.1	2.0 ± 1.7
Stature (cm)	175.3 ± 8.7	0.01 ± 0.34§
Nordic force (N)	347 ± 70	32 ± 48
Nordic force Imbalance	9.3 ± 6.8	0.4 ± 9.3
CMJ jump height (cm)	35.0 ± 5.2	1.2 ± 1.3
5 m (s)	1.00 ± 0.06	-0.02 ± 0.06
20 m (s)	3.02 ± 0.14	-0.06 ± 0.09
30 m (s)	4.31 ± 0.19	-0.07 ± 0.12
505-agility right (s)	2.51 ± 0.08	-0.09 ± 0.09
505-agility left (s)	2.52 ± 0.08	-0.08 ± 0.09

Individual correlations between all change score variables (physical fitness and growth) across the season are reported in Table 4.6 and Table 4.7. All change in sprint times had a very large to almost perfect association (ranging from r = 0.73, very large to r = 0.95, almost perfect), change in 505-agility left and right had a large association (r = 0.54, large; *p* = 0.0024). Improved CMJ jump height had a moderate association to improved 20 m (r = -0.42, moderate; *p* = 0.0145) and a large association to 30 m (r = -0.55, large; *p* = 0.0194) sprint times, but not changes in 5 m, nor change of direction scores. Increased stature had a large association to increased body mass (r = 0.59, large; *p* = 0.0004) and moderate associations to improved 30 m sprint time (r = 0.42, moderate) and increased NF imbalance (r = 0.31, moderate). Improved CMJ was moderately associated to increased stature (log transformed data, r = 0.47, moderate; *p* = 0.0066) and body mass (r = 0.48, moderate; *p* = 0.0050).

Table 4.6. Pairwise correlations of growth and physical fitness development.

Variable comparison	Body mass (kg)	Stature (cm)§	NF (N)	NF Imbalance (%)	CMJ jump height (cm)	5 m (s)	20 m (s)	30 m (s)	505-agility right (s)	505-agility left (s)
Body mass (kg)	n/a	0.59^^	0.07	0.04	0.48^	-0.26	-0.27	-0.30^	0.10	0.09
Stature (cm)§	0.59^^	n/a	0.00	0.31^	0.47^	-0.16	-0.22	-0.42^	0.07	0.23
Nordic force (NF) (N)	0.07	0.00	n/a	-0.18	0.10	0.03	0.20	0.12	0.17	-0.03
NF Imbalance (%)	0.04	0.31^	-0.18	n/a	0.07	-0.12	-0.02	-0.03	-0.01	0.09
CMJ jump height (cm)	0.48^	0.47^	0.10	0.07	n/a	-0.27	-0.42^	-0.55^^	0.25	0.19
5 m (s)	-0.26	-0.16	0.03	-0.12	-0.27	n/a	0.73^^^	0.76^^^	-0.02	-0.06
20 m (s)	-0.27	-0.22	0.20	-0.02	-0.42^	0.73^^^	n/a	0.95^^^^	0.13	0.07
30 m (s)	-0.30^	-0.42^	0.12	-0.03	-0.55^^	0.76^^^	0.95^^^^	n/a	0.09	0.05
505-agility right (s)	0.10	0.07	0.17	-0.01	0.25	-0.02	0.13	0.09	n/a	0.54^^
505-agility left (s)	0.09	0.23	-0.03	0.09	0.19	-0.06	0.07	0.05	0.54^^	n/a

^indicates a correlation > 0.30; ^^ a correlation > 0.50, ^^^ a correlation > 0.70, and ^^^^ a correlation > 0.90; CMJ, counter movement jump; imbalance, imbalance between limbs; § log transformed.

Table 4.7. Individual Pairwise correlations of growth and physical fitness development Continued on following page.

Variable comparison				
Variable 1	**Variable 2**	**Correlation**	**95% Confidence interval**	**^{1}*p*-value**
Nordic force (NF) Imbalance (%)	NF (N)	-0.18	-0.4304 to 0.1050	0.2176
Stature (cm)	NF (N)	-0	-0.3549 to 0.3538	0.9974
Stature (cm)	NF Imbalance (%)	0.31	-0.0499 to 0.5985	0.0897
Body mass (kg)	NF (N)	0.07	-0.2948 to 0.4112	0.7222
Body mass (kg)	NF Imbalance (%)	0.04	-0.3206 to 0.3872	0.8388
Body mass (kg)	Stature (cm)	0.59	0.2996 to 0.7767	0.0004***
CMJ (cm)	NF (N)	0.1	-0.2536 to 0.4271	0.5866
CMJ (cm)	NF Imbalance (%)	0.07	-0.2832 to 0.4007	0.7129
CMJ (cm)	Stature (cm)	0.47	0.1457 to 0.7037	0.0066**
CMJ (cm)	Body mass (kg)	0.48	0.1623 to 0.7122	0.0050**
5 m (s)	NF (N)	0.03	-0.3187 to 0.3675	0.8787
5 m (s)	NF Imbalance (%)	-0.12	-0.4426 to 0.2357	0.5163
5 m (s)	Stature (cm)	-0.16	-0.4779 to 0.2047	0.3969
5 m (s)	Body mass (kg)	-0.26	-0.5571 to 0.0989	0.1528
5 m (s)	CMJ (cm)	-0.28	-0.5595 to 0.0717	0.1182
20 m (s)	NF (N)	0.2	-0.1560 to 0.5068	0.2695
20 m (s)	NF Imbalance (%)	-0.02	-0.3633 to 03230	0.8995
20 m (s)	Stature (cm)	-0.22	-0.5311 to 0.1353	0.218
20 m (s)	Body mass (kg)	-0.27	-0.5646 to 0.0882	0.1369
20 m (s)	CMJ (cm)	-0.42	-0.6608 to -0.0900	0.0145*
20 m (s)	5 m (s)	0.73	-0.5169 to 0.8554	< 0.0001****
30 m (s)	NF (N)	0.12	-0.3711 to 0.5528	0.6470
30 m (s)	NF Imbalance (%)	-0.03	-0.4867 to 0.4466	0.9196
30 m (s)	Stature (cm)	-0.42	-0.7495 to 0.0757	0.0931
30 m (s)	Body mass (kg)	-0.3	-0.6823 to 0.2111	0.2420

Table 4.7. Continued.

Variable comparison				
Variable 1	**Variable 2**	**Correlation**	**95% Confidence interval**	**[1]*p*-value**
30 m (s)	CMJ (cm)	-0.55	-0.8065 to -0.1044	0.0194*
30 m (s)	5 m (s)	0.76	0.4519 to 0.9050	0.0003***
30 m (s)	20 m (s)	0.95	0.8603 to 0.9804	< 0.0001****
505-agility right (s)	NF (N)	0.17	-0.2193 to 0.5088	0.3942
505-agility right (s)	NF Imbalance (%)	-0.01	-0.3798 to 0.3663	0.9683
505-agility right (s)	Stature (cm)	0.07	-0.3088 to 0.434	0.7134
505-agility right (s)	Body mass (kg)	0.1	-0.2875 to 0.4527	0.6275
505-agility right (s)	CMJ (cm)	0.25	-0.1315 to 0.5625	0.1966
505-agility right (s)	5 m (s)	-0.03	-0.3876 to 0.3450	0.8992
505-agility right (s)	20 m (s)	0.1347	-0.2439 to 0.4776	0.4861
505-agility right (s)	30 m (s)	0.09	-0.3953 to 0.5328	0.7290
505-agility left (s)	NF (N)	-0.03	-0.4000 to 0.3455	0.8729
505-agility left (s)	NF Imbalance (%)	0.09	-0.2897 to 0.4509	0.6359
505-agility left (s)	Stature (cm)	0.23	-0.1612 to 0.5521	0.2487
505-agility left (s)	Body mass (kg)	0.09	-0.2962 to 0.4451	0.6619
505-agility left (s)	CMJ (cm)	0.19	-01941 to 0.5169	0.3351
505-agility left (s)	5 m (s)	-0.06	-0.4187 to 0.3119	0.7507
505-agility left (s)	20 m (s)	0.07	-0.3052 to 0.4248	0.7218
505-agility left (s)	30 m (s)	0.05	-0.4232 to 0.5084	0.8301
505-agility left (s)	505-agility right (s)	0.54	0.2196 to 0.7582	0.0024**

[1] All significant *p*-values are labelled accordingly: *< 0.05, **< 0.01, ***< 0.001, ****< 0.0001; CMJ, counter movement jump; imbalance, imbalance between limbs; Stature, log transformed stature.

4.6 Discussion

The main aim of this study was to explore the impact of HSI on physical development and match exposure time in elite academy footballers, over the course of a season. Currently, only limited findings are available to understand the impact that HSI could have on an EPPP academy player's physical development prior to elite senior level football.

The study highlighted some important findings relating to HSI impact. Significant differences were demonstrated between HSI and age of participants (14.1 to 23.0 years; MD, -2.1 years; 95% CI, -3.6 to 0.7 years; $p = 0.0053$), similar to previous findings that showed the risk that aging has on HSI in senior footballers (18.0 to 32.6 years; MD: 2.8 years; 95% CI=1.1 to 4.5 years; $p = 0.002$) (Timmins *et al*., 2016a). Older playing squads also had higher rates of HSI occurrences; all three grade III (range, 27 to 33 days injured) were in U21 players. Again, this is comparable to previous findings where professional players aged 17 to 22 years demonstrated a lower risk of HSI occurrence than players aged 23 to 35+ years (Woods *et al*., 2004). These findings suggest that HSI risks from non-modifiable aging effects are apparent within elite academy footballers up to the age of 23.0 years. These findings are vital as they provide an indication that older academy players are at greater risk of HSI. This begs the question, as to why this is. The greater level and intensity of training exposure to which older age groups are exposed could be considered as an additional factor influencing injury severity (Read *et al*., 2018b; Tears, Chesterton and Wijnbergen, 2018). In addition, older players may continue to play through impairment and soreness (Eirale, 2018), which is possibly associated with the pressures and intensity to which players are exposed as they move closer to becoming senior players (Saward *et al*., 2020). This highlights the importance of monitoring load and load responses in older academy players to help mitigate injury risk, particularly as prescribing load is vital to facilitate appropriate dose-response relationships to mitigate injury whilst maximising performance with factors such as congested match fixtures (Akubat, 2012). It should also be considered that when comparing different age groups/ squads, their prescribed training and match loads will likely differ.

Participants playing in the wing position sustained the highest amount of HSI (3 participants), followed by strikers (2 participants). Typically, wide midfield and forward related positions involve specific movement patterns, with greater rapid accelerations and high-speed running volumes, performed at a higher maximum velocity (Di Salvo *et al*., 2009; Bradley *et al*., 2009), all of which relate to HSI (Duhig *et al*., 2016; Evans and Williams, 2017). Furthermore, these movement patterns are used more frequently by players in the wing positions compared to other playing positions (Buchheit *et al*., 2010a). Future research could examine the impact of positions and positional demands on HSI in EPPP academy players. This could also mean preventive techniques revolve around positional requirements to a greater extent (Bourne *et al*., 2018).

Previous findings from elite senior footballers and AFL players support the hypothesis that those who sustain a HSI can be disadvantaged (e.g., Woods *et al*., 2004; Verrall *et al*., 2001). Players sustaining a HSI were absent from training and matches for 10 days (median) (range, 1 to 33 days) and missed 1 match (median) (range, 0 to 5 matches) across the season, although match exposure time for players sustaining a HSI was no different to that of players who did not sustain a HSI. Despite there being no significant differences between the HSI and no HSI groups, a large amount of valuable match exposure time was lost (MD, 409 mins; 95% CI -158 to 977 mins, p = 0.1541). This amount of match time lost is greater than a whole pre-season (343 mins ± 124), or comparable to an in-season phase (415 mins ± 234) average match time, for EPPP footballers (17 ± 1 years) (Noon, 2016). A HSI sustained within the testing period could have resulted in players needing extended time to recover physically and to re-establish themselves within the match day squad, despite being available for selection following rehabilitation. Players may also lack the confidence and motor unit activation to run at higher velocities in the acute periods after sustaining a HSI, especially if the action initiated the injury (Duhig *et al*., 2016; Thelen *et al*., 2005). This lack of confidence could result in reduced performance, leading to the injured player being overlooked for match selection. This missed opportunity for match selection would likely have an impact on players' technical and tactical playing development (Jones *et al*., 2019).

Previous research suggests that lower levels of eccentric hamstring strength increase the risk of HSI in footballers (Timmins *et al*., 2016b). Measurement of NF obtained during the performance of NHE can help to identify those athletes at risk of future HSI (Opar *et al*., 2014; Timmins *et al*., 2016a) and highlight whether any strength improvements have been achieved. Yet, it is acknowledged that prediction of injury is a complex problem. For example, elite senior footballers with lower levels of NF were 4.4 times more likely to sustain a HSI than stronger athletes (NF cut off < 337 N, relative risk (RR) = 4.4; 95% confidence interval (CI) 1.1 to 17.5 N; p = 0.013) (Timmins *et al*., 2016a). However, if an athlete sustains a HSI it is important to focus rehabilitation on strengthening the hamstring architecture and correcting hamstring asymmetrical dominance to a level where the athlete is not at further risk of re-injury, as those with a previous history have reduced hamstring strength, short biceps femoris fascicles and display the highest incidence of hamstring strains (e.g., Verrall *et al*., 2001; Croisier *et al*., 2008; Dauty *et al*., 2016; Bourne *et al*., 2018). HSI impaired eccentric knee flexor strength development in the EPPP academy footballers involved in this study. These strength reductions may be a result of extended absence from performing activities such as the NHE, initiating maladaptive processes such as, neural inhibition and prevention of hypertrophy and sarcomerogenesis of recently injured limbs (Timmins *et al*., 2015). Additionally, players can utilise compensatory strategies to prevent further damage to injured areas even in the short-term (Opar *et al*., 2012a). Therefore, it is necessary to select the correct exercise and protocol to engage and activate specific muscles during rehabilitation, dependent on the nature of the HSI injury (Bourne *et al*., 2018). Stimulus prescription can be more meticulously applied to individual players depending on their physiological profiles. Research can contribute to protocols for strengthening interventions focussed on the hamstring's architecture, function and morphology; any interventions should be designed to mitigate HSI risk (Bourne *et al*., 2018). This reinforces the value of academies employing injury and physical screening data to prescribe interventions, which could utilise HSI preventive methods other than the NHE (Bourne *et al*., 2018).

As discussed, greater NF change scores were observed across the season in the non HSI group, suggesting a negative impact of HSI by impairing NF strength improvements (MD, 47 N; 95% CI, 3 to 91 N; $p = 0.0378$). This relationship has been shown previously in adults observing hamstring strength changes across an AFL pre-season, comparing players sustaining a HSI in the previous 12 months against those who did not (MD, 40.7 N; 95% CI, 1 to 80 N; $p = 0.012$) (Opar *et al*., 2015a). However, it has been acknowledged that when comparing cohorts from different sports for HSI, risk factors should be examined with caution because, for example, of differences in exposure demands (Lee Dow *et al*., 2021). Yet, a negative association between pre-season scores and NF changes was found. Further inspection demonstrated that regardless of HSI status, players who achieved a NF score ≥ 365 N (outside the error associated with change in mean force) at pre-season did not gain NF strength by the end of the season. This suggests that the TL prescribed was of insufficient stimulus, and that once a certain level of NF strength is achieved from the NHE, additional load is required to further neuromuscular adaptations in order to improve and break through the ceiling effect. Recent studies involving the addition of load have demonstrated superior gains and adaptations (Bourne *et al.*, 2018; Pollard *et al.*, 2019). For example, Pollard and colleagues found that when individuals completed a 6-week NHE training intervention, those performing the NHE with additional weight increased NHE to a greater extent (MD, 82 N; 95% CI, 2 to 161 N; p = 0.044) than those completing the NHE with no additional load (MD, 67 N; 95% CI, -23 to 158N, p = 0.137) (Pollard *et al.*, 2019). Future research examining NHE loading effects on HSI occurrence and improving NF strength within academy footballers would be insightful. In some cases, outcomes may be a function of the focus of training; those players who remain fit and healthy do not engage and or make an effort to improve, but simply do enough to maintain strength over the season. Furthermore, effectiveness in activating the BF during eccentric loading could also be mitigated by neuromuscular inhibitions. These include loss of the full range of activation of muscle fibres, variations in synergistic muscle contributions enabling force production, or reduced coordination of motor unit firing, governed by central nervous system fatigue (Bourne *et al.*, 2018; Davis and Walsh, 2010). The importance of increasing hamstring strength, promoting strength overloads for HSI prevention and performance within the pre-season has been highlighted (Askling, Karlsson and Thortensson, 2003). Research found that adult AFL players with NF strength levels < 256 N at the start of the pre-season are 2.7-fold (RR, 2.7; 95% CI, 1.3 to 5.5; p = 0.006) more likely to sustain a future injury. The same was true of elite footballers with NF strength levels ≤ 337 N (RR = 4.4; 95% CI 1.1 to 17.5) (Opar *et al.*, 2015a and b). These findings suggest that it would be beneficial to get those footballers who have weaker hamstring strength to improve their strength at a quicker rate at the start of the season since HSI impairs hamstring strength. However, differences between senior and academy players must be considered, and findings from senior players cannot be considered definitive for academy players. Prevention of HSI occurrence is particularly important within the pre-season as strength development would be affected and this is an important phase of the season in which to condition players sufficiently to cope physically for the remainder of the season (Jeong *et al.*, 2011). In athletes who have greater hamstring strength introducing a different stimulus, varying the volume, intensity and introducing different hamstring-based strengthening exercises may be beneficial. Also, applying a detailed examination on the hamstrings' architectural and morphological structures could have implications on strength improvements, irrespective of whether they have sustained a previous HSI (Bourne *et al.*, 2018).

In contrast to previous findings, using isokinetic testing within academy footballers (RR = 4.66; 95% CI: 2.0 to 10.8) (Croisier *et al.*, 2008), a disparity of between limb-balance at pre-season was not demonstrated amongst those who had a HSI in this study compared to those who did not (MD -3.6 %; 95% CI, -9.0 to 2.0%; p = 0.1907). Also, no significant differences were observed for limb-imbalance change scores between the two groups (MD -1.3 %; 95% CI, -10.2 to 7.5%; p = 0.7624). However, this could be due to the differences in the assessment equipment and how efficiently the protocols can be undertaken. For example, the NordBord testing protocol is conducted quickly and measures limb imbalance with one test compared to the need for two separate tests for each limb required for some isokinetic testing. However, as reported previously the associations of HSI risk with asymmetrical hamstring dominance from bilateral testing have differed in adult athletes (Timmins *et al.*, 2016b).

Significance was shown between HSI and body mass changes across the season, with participants without HSI injury gaining more body mass across the season (MD, 1.7 kg; 95% CI, 0.1 to 3.3 kg; p = 0.0427). This could be due to these individuals being able to perform more resistance-based sessions targeting and involving the hamstrings, to prevent maladaptive processes and decreases in skeletal-tissue size (Koundourakis *et al*., 2014). This hypothesis could be investigated further by reviewing time spent absent from performing resistance-based exercise in gym-based sessions, or the impact of any contact and non-contact injury within EPPP academy footballers.

Despite the differences observed in NF development, the other physical fitness measures including sprints (5, 20, 30 m), 505-agility and CMJ changes across the season were no different between the HSI groups. This suggests that sustaining a HSI had no impact on these measures. These findings differ from the original hypothesis in which it was thought that HSI would have an impact on development in sprint velocity-based training, which has been shown in detraining effect studies for as little as two weeks breaks in training (Rodríguez-Fernández *et al*., 2018).

Correlations were demonstrated between some of the change scores across the testing period. Changes in CMJ were associated with growth (ranging from r = 0.47, moderate – 0.48, moderate) (body mass and stature) and changes in sprint times (ranging from r = -0.42, moderate – 0.55, large) (20, 30 m) demonstrating that physical fitness development across the season could be a function of growth, similar to previous literature (Hammami *et al*., 2013). However, these improvements could depend on whether neurological adaption has occurred in response to these possibly rapid growth changes (Read *et al*., 2018a). Relationships between strength, sprint and jump performance (ranging from r = 0.596, large – 0.762, very large) have been shown previously within a similar cohort highlighting the importance of developing lower body strength in academy footballers to increase jumping and sprinting capabilities (Comfort *et al.*, 2014). In previous research, implementation of a NHE programme for 27 sessions over a 10-week pre-season training period in a small sample group of elite senior footballers (n = 19) demonstrated some physical performance improvements. Players (6 out of 9) improved in both short distance (5 and 10 m) sprint times compared to players without this intervention; no improvement was observed in either group for 30 m sprint times (Krommes *et al*., 2017). Players in both groups improved in CMJ jump height with the NHE group players (6 out of 9) having greater improvement (Krommes *et al*., 2017). Findings such as these, provide evidence of the need to apply specific strength interventions and measures such as the NHE to facilitate physical development. However, the present study found no associations with changes in NF, indicating that the relationships between the physical fitness development measures in the present academy cohort could be primarily focussed on concentric-actions. An exposure to an eccentric stimulus is required for HSI prevention, with known associations to the mechanisms of sprinting (e.g., Bourne *et al*., 2018; Opar *et al*., 2012a and b). Greater insight into eccentric strength effect on other physical fitness characteristics would be insightful in additional cohorts, as well as the relationships of both training and match exposure with physical development. However, it must be acknowledged that examination of these correlations does not indicate causation, but hints instead at possible influence (Ryan *et al*., 2018).

To build on from Study 1, more expansive monitoring approaches could be employed within additional cohorts. Whilst HSI has been demonstrated to result in significant absence from competition and training (Read *et al*., 2018b). Observations of all non-contact injuries, against training and match activity allow for a more holistic analysis of the impact of non-contact injury (Jones *et al*., 2019; Ward *et al*., 2007). Additionally, more physical fitness measures could be incorporated, applicable to other common anatomical injury sites in academy footballers. Finally, a notable omission of the present study is the examination of training and match loads to which players are exposed. Added load measures will be employed within the following study to examine the influence of exposure.

4.6.1 Limitations

There are recognised limitations within this current study. There are no external load data acknowledging movement distance and velocities at which the participants perform, such as measurement of HSR. If used, detailed external load data would allow for greater insight of training and match exposure in relation to time, injury occurrence as well as linking to multiple physical fitness measures. The data from physical fitness (sprinting, jump and change of direction) and growth was not as complete in comparison to the other variables, although there were missed data points across all variables. This study was restricted to a cohort of EPPP academy football players from one professional environment, both of which should be acknowledged when relating to different athletic groups. Since this was a longitudinal research study within one professional environment the participant cohort consisted of a total of 55 participants. Ideally, a greater number of testing time points with complete data sets, could be used in the future. However, the number of testing points is reflective of the environment with testing procedures adapting to the schedule for the participants. Although some insightful findings are reported within this study, the conclusions should be viewed with caution due to the small sample size involved. It is acknowledged that the study is exploratory in nature therefore it should be considered as an observational starting point, not as a conclusive investigation. To account for type 1 error, *t*-tests were conducted without Bonferonni corrections. Though these corrections have been considered within some research examinations based on higher numbers, application of such a correction would have been detrimental in the present exploratory project, as determination of significance would be difficult due to multiple measures being examined. Full limitations are discussed in Chapter 7.

4.6.2 Conclusions

EPPP academy footballers who sustained a HSI injury within a season displayed impaired NF across that season, compared to those who had not sustained a HSI. The impact of HSI on player's availability for competition, and their ability to increase their hamstring strength is apparent. This may have an impact on the academy footballers' tactical and skill development and progression to attain a professional contract or, to move up an age group within the academy. Clearly, it is important to protect EPPP academy footballers from HSI. Consequently, the introduction of NHE testing over a longitudinal period would be beneficial in monitoring these players for HSI risk, especially when players are recovering from a previous HSI. Furthermore, to maximise neuromuscular adaptations, exercise prescriptions can be applied specifically for individuals which can be directed by the same monitoring procedures. Development of vertical jump performance could support improvement in pitch-based running speeds and *vice versa*. Additionally, physical fitness development such as vertical jump performance could reflect increases in growth. Examination of the relationships of numerous physical measures can give practitioners an indication of which stimuli and physiological adaptations could facilitate mechanisms conducive to players' development.

Chapter 5: Study 2

An exploratory examination of physical factors to support the development of elite academy footballers

5.1 Abstract

Objectives. To assess the impact of reduced availability due to non-contact injury on players' physical development and their training and match exposure. To identify potential risk factors at pre-season which could lead to reduced availability. To examine relationships, independent of injury, between growth and physical fitness development, training and match exposure. In addition, to compare physical differences between players who were successful at achieving elite senior first team status against those who were not.

Design. A longitudinal observational study over a complete EPPP season with comparisons between availability groups and multiple physical and exposure measures and career progression.

Participants. Footballers from a single EPPP category 1 academy (15.9 to 18.5 years; stature 176.5 ± 6.5 cm and body mass 68.9 ± 6.7 kg) from U18 squad (n = 25).

Main outcome measures. The training sessions and matches missed due to non-contact injuries and time–motion analyses, were recorded across a season. Growth and physical fitness measures were recorded at the first pre-season test and last test of the season, and career progression established one season post-testing.

Results. Low availability due to non-contact injury resulted in significantly less opportunity for players to train and be involved in competitive matches. Low availability led to less exposure to cumulative PlayerLoad and covered total distance within training.

The same was true during matches, though low availability also led to less HSR, explosive distance and sprints. Pre-season physical fitness revealed that the sit and reach and CMJ peak landing force asymmetry scores discriminated between high and low availability groups, where the high availability group had lower scores (sit and reach: MD, -9.8 cm; 95% CI, -16.9 to -2.8 cm; $p = 0.0091$) (CMJ peak landing force asymmetry: MD, -14.86%; 95% CI, -29.14 to 0.57%; $p = 0.0422$) compared to the low availability group. No physical fitness or growth development measures differentiated between groups. Independent of injury, growth development was correlated with physical fitness development; for example, increases in NF with increased growth (e.g., body mass: r = 0.48, moderate; $p = 0.0455$). A link was observed through associations between training and match exposure variables for total PlayerLoad (r = 0.76, very large; $p < 0.0001$) and high-speed running (r = 0.74, very large; $p < 0.0001$). Training and match exposure were also associated with development in physical fitness as evidenced by CMJ parameters, hip and groin strength. Examples include: improved CMJ jump height with increased training (r = 0.62, large; $p = 0.0043$) and match total PlayerLoad (r = 0.46, moderate; $p = 0.048$). Those successful in achieving senior first team status (n = 2) at an earlier stage in their careers had high availability, began the season taller (MD, 1.6 cm; 95% CI, 0.1 to 2.9 cm; $p = 0.0327$) and were stronger (e.g., CMJ jump height (MD, 1.8 cm; 95% CI, 0.4 to 3.1 cm; $p = 0.0134$).

Conclusions. Reduced attendance at training sessions and matches because of non-contact injury may not impact on players' physical development even with decreased exposure to training and match stimuli; specifically, total PlayerLoad, total distance, HSR, explosive distance and sprints. Higher sit and reach scores can discriminate between those who have low or high availability, highlighting possible hypermobility in players with lower availability. Hypermobility, possibly associated with growth spurts, may be an important aspect to be examined in these young players. CMJ peak landing force asymmetrical dominance also emphasises lower availability, indicating neuromuscular control might be worth investigating further. There are multiple relationships between growth and physical fitness development variables such as improved NF with increases in growth. Therefore, growth should be accounted for when monitoring changes in physical fitness. There are also multiple relationships between training and match exposure and variables of growth and physical development (e.g., CMJ parameters and high-speed running). This may suggest that greater levels of training exposure and parameters of physical strength could influence the extent of some match exposure stimuli. Footballers successful in progressing to the senior first team the season after playing for the U18s, are taller and stronger compared to others and had high availability the previous season.

5.2 Introduction

Injury incidences in elite youth footballers play a significant part in their playing availability, potentially affecting their ability to develop physically and improve their performance levels and playing standard (Jones *et al*., 2019). Higher injury rates and severity in youth footballers are particularly common in older age groups (U16 to U18) of elite football academies where they are exposed to high-volume training programmes (Read *et al.,* 2018a and b; Renshaw and Goodwin, 2016; Tears, Chesterton and Wijnbergen, 2018). Multiple athletic related internal (intrinsic), and external (extrinsic) environmental factors can be examined by means of physical fitness, growth and exposure measures. These can be utilised to identify risk factors for injury and review performance and physical changes, all of which have relevance to elite level football (Buchheit *et al*., 2013; Noon *et al*., 2015; Read *et al*., 2018a). Measures of football-specific physical fitness and growth development, training and match exposure levels are used as standard practice within EPPP academies (Noon *et al*., 2015; Read *et al*., 2018a) and other elite youth and senior football environments (e.g., Buchheit *et al*., 2013; Casajús, 2001; Hammami *et al*., 2013; Reilly and Doran, 2003; Vänttinen *et al*., 2011). In an elite youth football setting, these growth and performance measures can be implemented, to monitor physiological adaptations, fundamental physiological and exposure stressors and neuromuscular systems (Bowen et al., 2017; Comfort *et al*., 2014; Read et al., 2018a). It is clear that physical development across a season could be better determined by application of a longitudinal design to monitor growth and physical fitness in which the repeatability of measures is controlled from an initial baseline to an end-point. Thus, when coupled with exposure data collected cumulatively across the same season, examinations can be made of the interrelating relationships that growth and physical fitness development and training and match exposure have on each other (Cobley and Till, 2017; Lloyd *et al*., 2014; Meyers *et al*., 2017; Spencer *et al*., 2011; Wrigley *et al*., 2014). Whilst correlation does not indicate causation, analysis of physical fitness components that can be targeted to improve specific training and match exposure demands, and identification of those components that could influence physical development, can support decision making in football academies (e.g., Malina *et al*., 2004; Rebelo *et al*., 2016; Ryan *et al*., 2018; Williams, Oliver and Faulkner, 2011). This includes the function of growth on physical development and exposure. Furthermore, there is limited research that has examined the impact of reduced playing (training and competition) availability due to non-contact injury, on player's physical development and their exposure levels, over a season in elite level academy football.

Some of the intrinsic and extrinsic measures used to measure physiological changes for growth and performance in players and their exposure levels can also be applied to examine their associations to chronic fatigue and injury occurrence (Price *et al.*, 2004). Intrinsic risk factors can pre-dispose the athlete to injury that manifests in deficiencies such as fitness, joint mobility, muscle tightness and weakness, motor abilities and specific sports' skills proficiency (Fousekis *et al.*, 2011; Meeuwisse, 1994a and b). While extrinsic risk factors, such as the training volume and intensity can make a pre-disposed athlete susceptible to injury (Ehrmann *et al.*, 2016; Meeuwisse *et al.*, 2007), it might be anticipated that by highlighting intrinsic risk factors, physical interventions can be applied to bring players within suitable physical ranges and so help to alleviate injury risk. Through extrinsic monitoring, training and match loads and recovery time between physical activities can be prescribed specifically to individual players, to enable tolerance to cumulative exposure, facilitating optimal performance whilst mitigating the risk of injury (Bowen *et al.*, 2017; Brink *et al.*, 2010). Tests to identify intrinsic and extrinsic risk factors for injury are formulated typically from clinical experience (Gabbe *et al.*, 2004) and can be determined by various means including knowledge of testing protocols, accuracy, measurement time, cost and access to equipment. For elite youth and senior footballers, the pre-season period has been highlighted as a critical prediction period to monitor for injury risk for the upcoming season (e.g., Bradley and Portas, 2007; Kiesel, Plisky and Voight, 2007). Also, players are at a greater risk of injury within the pre-season period, or the early start of the season (September) (Le Gall *et al.*, 2006; Price *et al.*, 2004; Woods *et al.*, 2002). This is likely due to rapid increases in load (often referred to in the literature as 'spikes') (Duhig *et al.*, 2016) from intense training to which the players do not adapt effectively (Price *et al.*, 2004). Consequently, applying an effective battery of tests, which can inform support staff and coaches about multiple risk factors at the beginning of pre-season period, gives time for interventions to be prescribed to players, possibly reducing the likelihood of injury.

Injury risks, training and match experience have been shown to relate to playing standard and affect performance in elite youth footballers (Helsen *et al.*, 2000; Le Gall, Carling and Reilly, 2008), as well as physiological factors such as growth, fitness levels and maturity status (Gil *et al.*, 2007a and b; Le Gall *et al.*, 2010; Malina *et al.*, 2004). It is important for elite youth players to have the greatest level of neuromuscular physical fitness possible, as higher levels of strength, sprint speed, change of direction and maximal anaerobic power have been shown to relate to greater probability of achieving a higher playing standard (Le Gall *et al.*, 2010; Gil *et al.*, 2007a and b). Further insight into identifying those factors that can highlight a player's capabilities to progress to a high level of football would be of benefit to coaches and organisations (Le Gall *et al.*, 2010). However, the time in players' careers at which they progress could be dependent on their physical capabilities and requires further examination.

The main aims of this study, which involved EPPP academy footballers across a season, were first, to examine the impact of availability (training and competition) on growth and physical development and training and match exposure. Second, to examine the differences in multiple physiological measures (growth, physical fitness) taken at pre-season according to levels of availability. Third, to examine the relationships between growth and physical fitness development, training and match exposure, independent of injury. Finally, to identify any physical characteristics associated with players who are successful at gaining elite senior first team status. Such analyses should help to anticipate what measures would affect time out due to non-contact injury, and progression in physical performance and career progression.

5.3 Methods

5.3.1 Participants

All 25 participants were male elite youth academy football players from the same category 1 academy engaged in the full-time EPPP programme. They were all members of the U18 age group squad, aged from 15.9 to 18.5 years, stature 176.5 ± 6.5 cm, and body mass, 68.9 ± 6.7 kg. They were contracted to the club on a full-time scholarship and/or had a professional contract and were medically cleared to play at the start of the season on the basis of cardiac and medical screening by the club. Specific criteria outlined below determined participant’s inclusion. All participants, where age appropriate, provided written consent or assent, and their parents or guardians provided written consent prior to the start of testing (Appendix 1). Ethical approval for the study was given by the University of South Wales Ethics Committee (ethics code: 17JSMW0701) prior to all testing procedures.

5.3.2 Inclusion criteria

These were fixed; to be included, participants were required to be full time players within the U18 age group squad during the 2017/18 EPPP season and had to be contracted to the Academy before the commencement of pre-season training. They were required to have all their injury details and training and matches (total number and time–motion analyses of activity) recorded.

5.3.3 Design and procedure

A longitudinal observational study was conducted over 9 months from the start of pre-season until the end of the competitive EPPP season (August 2017 - April 2018). All testing sessions took place at the same training ground venue. Throughout the season (testing period) the following components were recorded: the total number of pitch-based training sessions and matches that took place, and the total number of these training sessions and matches that were missed due to non-contact injuries. Also, time–motion analyses were collected *via* GPS (OptimEye X4, Catapult Innovations, Melbourne, Australia; firmware v: 7.17) for completed training sessions and matches by all participants except for GKs (reasons explained in Chapter 3). Growth and physical fitness measures were collected, with the participant's first test of the pre-season (baseline) and their last test at the end of the season being utilised for this study. Testing sessions were conducted prior to the participants' athletic development sessions (prior to pitch-based training) within the weekly build up to matches. Participants, including those who had sustained any injury or were rehabilitating, were declared physically capable of performing any physical test and pitch-based training and matches prior to each testing session by the medical staff at the club. In all testing procedures, if the participant's scores indicated an issue, or they highlighted discomfort verbally prior to, during, or afterwards, they were directed to the organisation's medial staff available that day and were reviewed to determine the appropriate treatment. All participants were familiar with, and had completed, all of the testing procedures before the study commenced. All variables from the measures included are displayed within Table 5.1. Figure 5.1 shows the timeline of data collection of the physical and exposure measures included and the time points from which the change scores were calculated. The career progression of participants was reviewed one full season post testing.

Table 5.1. Variables included within the study separated into components.

Availability (training & matches)	**Participant details**	**Growth (anthropometric) screening variables**	**Physical fitness screening variables (flexibility & strength)**	**Time–motion analyses (Global Positioning System)**
Missed training sessions	Age (years)	Body mass (kg)	Sit and reach (cm)	Training total distance (m)
Missed matches	Position	Standing stature (cm)	Dorsiflexion lunge (left, right) (cm)	Training high speed running (m)
Missed total sessions	Career progression (senior first team)	Seated stature (cm)	Dorsiflexion lunge asymmetry (%)	Training explosive distance (m)
Training availability (%)			Counter movement jump (CMJ) concentric, eccentric mean force (N)	Training total PlayerLoad (au)
Match availability (%)			CMJ jump height (cm)	Training number of sprints
Total availability (%)			CMJ peak force (N)	Training sprint distance (m)
			CMJ concentric, eccentric mean force asymmetry (%)	Match total distance (m)
			CMJ take off, landing peak force asymmetry (%)	Match high speed running (m)
			Nordic force (N)	Match explosive distance (m)
			Nordic force imbalance (%)	Match total PlayerLoad (au)
			Adductor, abductor strength (hips 90^0 flexion) *via* GroinBar (N)	Match number of sprints
			Adductor, abductor strength (hips 60^0 flexion) *via* GroinBar (N)	Match sprint distance (m)
			Adductor, abductor strength (hips 90^0 flexion) *via* GroinBar imbalance (%)	
			Adductor, abductor strength (hips 60^0 flexion) *via* GroinBar imbalance (%)	
			Adductor strength (hips 45^0 flexion) *via* sphygmomanometer (mmHg)	

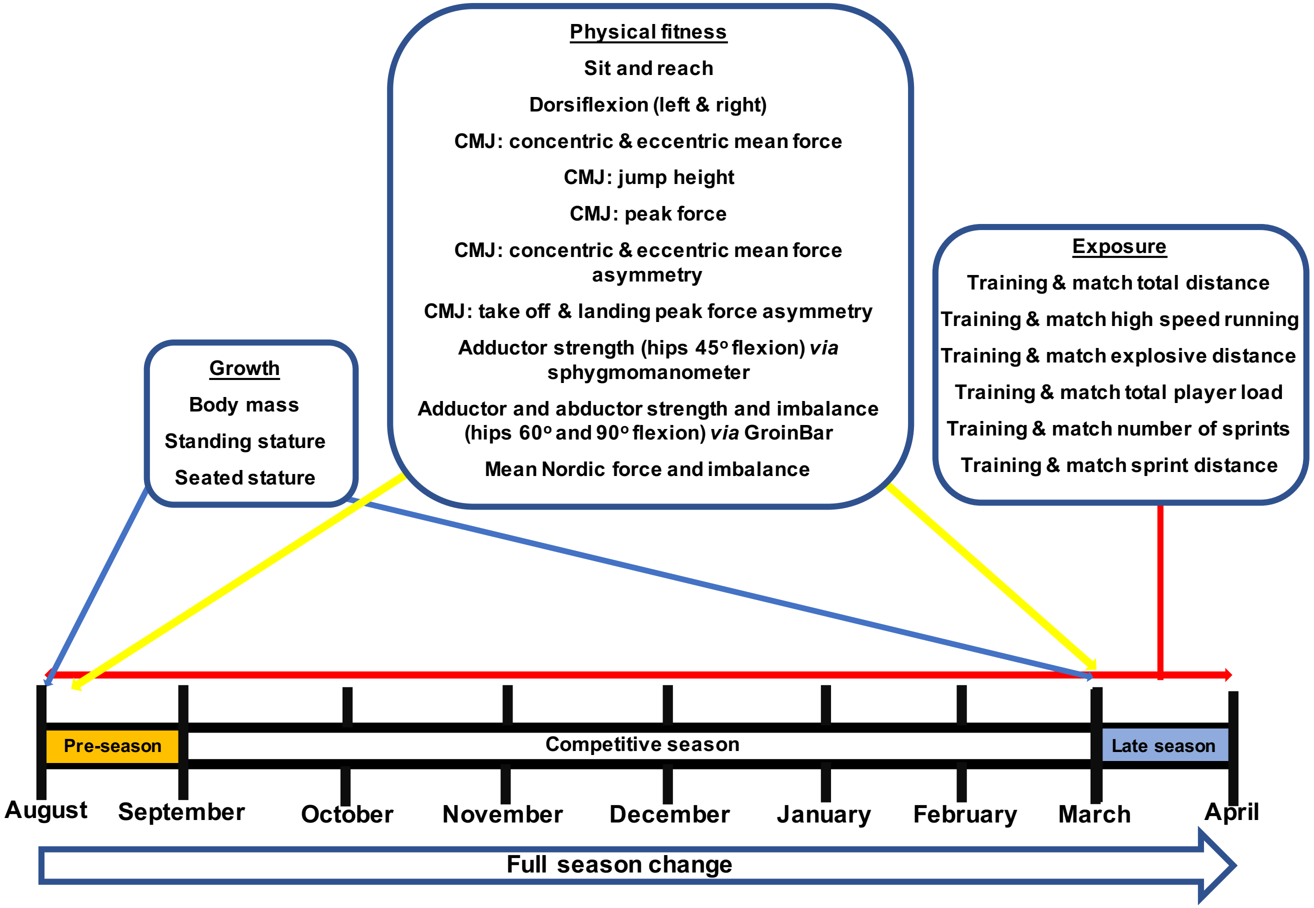

Figure 5.1. Timeline of physical measures included within the study. CMJ, counter movement jump. The thick white arrow shows the period over which change scores were calculated across the season. Coloured arrows (yellow, red and blue) indicate the time points at which physical measures were collected

5.3.4 Training and match availability

Participants' injury and playing details were collected prior to each training session and match throughout the season from U18 daily medical reports generated by the club's medical staff. The investigator was present for each session and communicated regularly with the medical staff, ensuring that there were no errors in collection of the studies' data (Wik *et al*., 2019). These details were categorised according to whether the participant had sustained any non-impact (contact) injury, diagnosed by the medical staff, resulting in them not being able to participate in any capacity with pitch-based (training and match) activity (excluding the day of injury) (Price *et al*., 2004). In addition, all pitch-based training sessions and matches across the season were recorded.

5.3.5 Participant details

Participant details comprised of age, playing position and career progression (senior first team status). Age was recorded in years. Playing position was assigned by the participants' most predominant playing position through the season. Positions were separated into GK, FB, CB, CM, WG and ST. Career progression was determined as a participant's inclusion in the match day squad for an elite senior first team competitive fixture one season post testing. When reviewing participants' career progression, achieving a professional contract was also examined, though due to the nature of differing contract details, this was not included within the analysis.

5.3.6 Growth and physical fitness measures

Full details of testing procedures and their reliability are given in Chapter 3.

5.3.6.1 Anthropometrics. Anthropometric *(*growth) data included body mass, standing and seated stature. Body mass (kg) was measured *via* digital floor scales. Stature (seated and standing) (cm), *via* a stadiometer (Model HR001, Tanita 148, Leicester) and a specifically designed growth and maturation 50 cm box (just for seated stature) (Perform Better, Warwickshire, UK).

5.3.6.2. **Sit and reach.** Participants placed the soles of their feet against the sit and reach box (Perform Better, Warwickshire, UK). Knees were locked in an extended position against the ground, with their hands on top of one another, palms facing downwards against the front of the scale. Participants reached forwards as far as possible pushing the scale, while keeping their fingertips against the scale throughout, posterior of limbs fixed to the ground and knees straight. The furthest reach position was held for 2 s and scores were recorded (cm) *via* the scale (Van Doormaal *et al*., 2017).

5.3.6.3 Dorsiflexion lunge. A pre-marked scale (cm) was fixed on the floor by a levelled wall (0 cm by wall junction). Participants aligned the foot of their leading leg, from the big toe to the heel, beside the tape on the floor, ensuring that their hip and knee were in line. They lunged forward flexing at the knee, attempting to touch the wall with their knee, ensuring their heel remained in contact with the floor. Maximum distance from the big toe to the wall for each foot was recorded (Bennell *et al*., 1998). Scores of left and right limbs and limb imbalance (asymmetry), defined as a percentage difference, were included within the analysis (Bell *et al*., 2014).

5.3.6.4 Counter movement jump. CMJs were performed using dual single axis force-platforms (PASPORT force platform PS-2141, PASCO, Roseville, California, USA), paired with NMP Force Decks software v1.2. 6348 (London, UK; VALD Performance, Albion, Queensland, Australia) sampling at 1,000 Hz. Prior to trials participants stood as motionless as possible for force curves to reach an uninterrupted horizontal state. Participants were instructed to aim for the greatest vertical height, dipping to their preferred degree (^{0}) of flexion of their knee joints, explode upwards, triple extending at the hip, knee and ankle, and land, with arms kept akimbo throughout (Hart *et al*., 2019). Three maximal trials were performed and the trial with the highest jump height (cm) was recorded for analysis (Ryan *et al*., 2018). Limb imbalance (asymmetry) was defined as a percentage difference (Hart *et al*., 2019).

5.3.6.5 Adductor and abductor strength. All tests were completed through dynamic bilateral isometric hip adduction or abduction in a supine position. Adductor strength was determined using two different pieces of equipment, a sphygmomanometer (pre-inflated to 40 mmHg) (Anierod sphygmomanometer, Sports physio supplies, Killinan, Ireland) and a specifically designed dynamometer (GroinBar) secured *via* a force frame (VALD Performance, Albion, Queensland, Australia).

Adductor tests involving the sphygmomanometer were performed with hip flexion at 45^0 flexion. The centre of the sphygmomanometer was positioned to the most prominent area of the medial femoral condyles. Participants would perform three maximal efforts, from which maximum pressure would be recorded for the highest point on the dial (Delahunt *et al.,* 2011). The highest score was rounded to nearest 5 mmHg and included for analysis.

Alongside adductor strength, abductor strength was tested *via* the GroinBar, from 60^o and 90^o hip flexion. Force data was collected from the left and right limb *via* force transducers (behind pads) sampling at 50 Hz, producing peak force (N) from each limb. Participants would flex hips at 60^o, the medial malleolus of the right leg was brought in line with the left tibiofemoral joint line followed by the left leg, flexing up so that the medial malleoli were aligned. Pads were positioned so their centre was at the most prominent point of the medial femoral condyles. Participants completed 3 maximal trials, separated by 10 s (O'Brien *et al*., 2019). Abductor strength followed in the same position with the outsides of the knees placed against outer lateral pads for three trials, adductor and abductor tests at 90^0 would follow, with protocols remaining the same. The highest peak M score from both lower limbs was recorded from 5 s of adduction and abduction, limb imbalance was calculated as a percentage difference (O'Brien *et al*., 2019).

5.3.6.6 Nordic force. The Nordbord field testing device (VALD Performance, Albion, Queensland, Australia), was used to assess NF *via* the NHE (Opar *et al*., 2013). Following previously described protocols (e.g., Opar *et al*., 2015a and b; Timmins *et al*., 2016a), participants knelt on the device with their ankles secured immediately superior to the lateral malleolus *via* separate ankle hooks. Once in position they performed the bilateral NHE with a warm-up set of three submaximal reps (approximately 70% of their maximal effort), then after 1-min one set of three reps at maximal effort. During trials, peak force was transferred to the L and R force transducers sampling at 100 Hz. Data analysis for NF was calculated *via* Peak NF (N) for each limb (left and right) with mean force of both limbs determined (N). NF limb imbalance was calculated as a percentage difference (Timmins *et al*., 2016a).

5.3.7 Time-motion analyses

Time–motion variables were recorded for pitch-based training sessions and matches by GPS devices with a 10 Hz engine (OptimEye X4, Catapult Innovations, Melbourne, Australia).

5.4 Statistical analyses

Statistical analysis was completed using JMP v 15.0 Pro Statistical Discovery Software (SAS Institute, Inc, Cart, North Carolina USA). Data is displayed as (M ± SD), or (MD, 95% CI, *p*), or (correlation coefficient (r); *p* (if significant)), unless indicated otherwise. Significance was set at a confidence of 0.95 ($p < 0.05$) and Cohen's *d* (effect size) was reported for comparisons where possible, the magnitude of the effect was interpreted as small, < 0.2; medium 0.5; and large 0.8 (Cohen, 1988).

$$d = \frac{|m_1 - m_2|}{\sqrt{\dfrac{(n_1\text{-}1)s_1^2 + (n_2\text{-}1)s_2^2}{n_1 + n_2\text{-}2}}}$$

Equation for Cohen's *d* (effect size) accounting for unequal *n*.

Where appropriate Shapiro-Wilk test was used to examine variables for normality (normal distribution). A log transformation was performed on variables which were not normally distributed and if after this they remained not normally distributed, they were not included within the analyses. Levene's test was used to examine equality of variance (homoscedasticity) between the availability groups. A flow-chart outlining the statistical analysis is displayed in Appendix 2.

Participants' availability was calculated as percentages (%) respectively, for training, matches and both training and matches combined (total availability). Ward's two-way hierarchical cluster analysis was used to categorise participants into homogeneous groups based on their match and training availability. The analysis identified two groups: a high availability group and a low availability group. The group classifications were confirmed, using a dendrogram and parallel plot. In addition, distributions of all the measures from each of the two availability cluster groups were calculated, providing descriptive statistics. To confirm the structural validity of the availability cluster groups, independent *t*-tests between training, match and total availability were performed. For analysis, all time–motion data across the season were totalled for each variable and for each participant. To demonstrate the magnitude of exposure differences between high and low availability groups independent *t*-tests were performed for the time–motion analyses variables.

Age was calculated by years from the date of birth to the first day of the pre-season (testing period). The change scores represented growth and physical fitness development over the season. Change scores were calculated as the end of season score minus the pre-season score, giving a change score total. From the physical fitness measures, improvements would show a positive score with exceptions of limb imbalance (asymmetry) (%) where a negative score would reflect an improvement.

The frequency distributions of playing position that populated the high and low play availability groups were determined. Due to the exploratory nature of the study, univariate analysis involving multiple independent *t*-tests examined the differences between the availability groups against age, pre-season and change scores of the growth and physical fitness variables. Bonferonni corrections were not performed to account for multiple comparisons as the study was exploratory in nature. To obtain the MD, mean values for the low availability group were subtracted from those for the high availability group.

When examining the relationships between physical development, training and match exposure, variables measuring the same outcomes (mechanisms) could potentially be repeated within the correlations of the large number of physiological variables (total n = 37, including variables not normally distributed). Consequently, a process of data reduction using pairwise correlations was completed. This involved first grouping the variables based on what feature they measured i.e., 1. Growth (change scores); 2. Physical fitness development (flexibility and strength change scores) and 3. Exposure. Pairwise correlations within the three groups of variables were performed to establish potential multicollinearity. Variables from measures that assessed the same specific mechanisms e.g., adductor strength were compared against each other. If two variables assessing the same specific mechanism were found to have very large or greater associations ($r \geq 0.70$) between each other, the most commonly used variable, as per the literature, was retained for analysis. Following the data reduction, pairwise correlation analyses between the growth and physical fitness development and exposure variables were assessed. For the final Pairwise correlations the following conditions were followed to examine the strength of correlations < 0.1 trivial, 0.1 to 0.3 small, 0.3 to 0.5 moderate, 0.5 to 0.7 large, 0.7 to 0.9 very large and 0.9 to 1.0 almost perfect (Hopkins *et al.*, 2000), alongside the significance ($p < 0.05$). Based on previous research within similar cohorts, considerations were given to the strength of the associations from the final Pairwise correlations (e.g., Comfort *et al.*, 2014; Malone *et al.*, 2015a).

Participants were separated into two career progression groups, according to whether they had been included in matches played by the senior first team of the organisation. These groups were compared against availability, age, position, pre-season physical measures, and time–motion analyses through profiling and graphing characteristics unique to participants achieving senior first team standards. Z-scores were used to compare measures against career progression groups and were calculated through a column standardisation formula. Multiple independent *t*-tests examined the differences between the career groups against the pre-season Z-scores of the growth and physical fitness variables.

5.5 Results

Training explosive distance, dorsiflexion lunge (left and right), adductor strength at 45^0 hip flexion, CMJ concentric mean force and peak force development were not normally distributed. For these variables, only CMJ peak force passed the Shapiro-Wilk test for normality ($p = 0.3151$) following a log transformation of the data. Therefore, variables of training explosive distance, dorsiflexion lunge, adductor strength at 45^0 hip flexion and CMJ concentric mean force were removed from the main analysis as they were still not normally distributed (all $p < 0.05$). All variables included in the study demonstrated equality of variance between the availability groups ($p > 0.05$).

5.5.1 Impact of reduced training and match availability

From hierarchical cluster analysis of the 25 participants (Figure 5.2), two groups were classified, a high availability group (n = 20), and a group with low availability (n = 5).

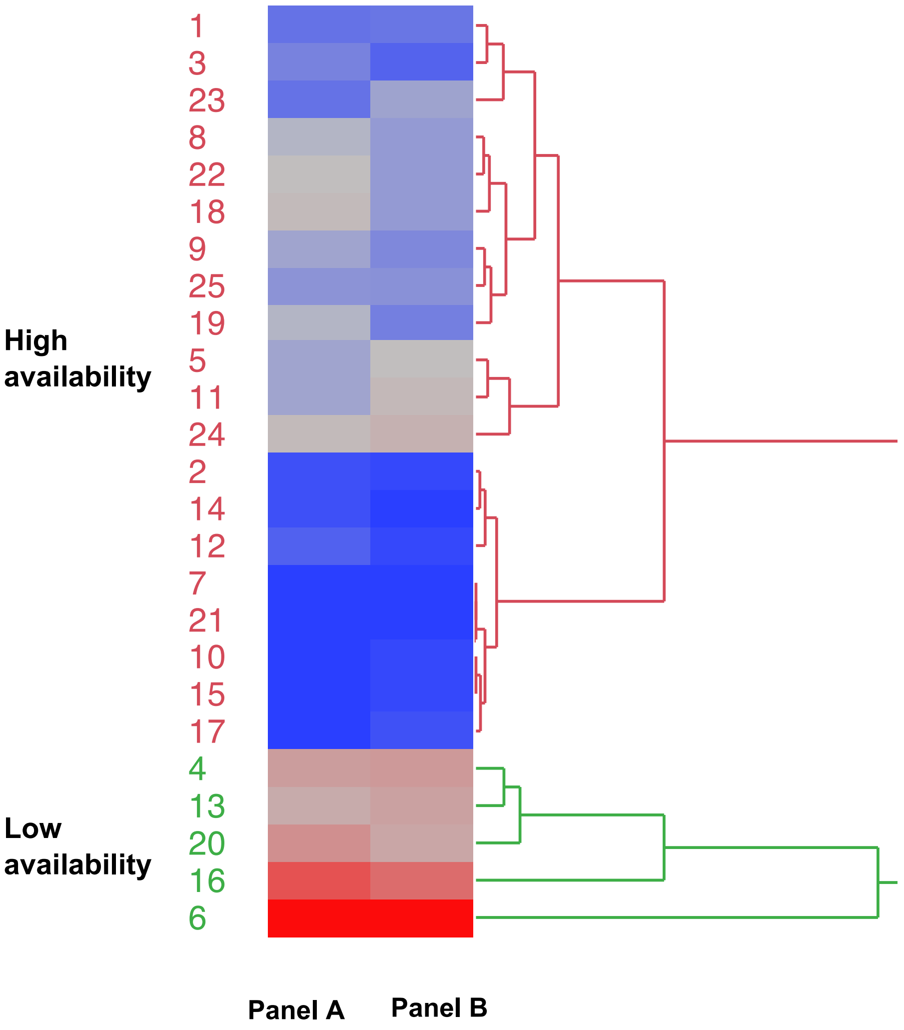

Figure 5.2. Hierarchical clustering dendrogram, separating high and low availability injury groups. Identification for individual participants is listed on the left-hand side of the figure. The colours indicate group membership: High availability (red numbers and blue shading), low availability (green numbers and red shading). Panel A (training availability), Panel B (match availability).

Structural validity of the high and low availability groups was confirmed by group differences in all training and match availability data (all $p < 0.0001$) shown in Table 5.2. The training sessions and matches missed across the season for each availability group are displayed in Table 5.3. Injury data for the low availability group is reported within Table 5.4. Both training and match exposure data discriminated between the two availability groups. Over the season, the high availability group were exposed to 16849 au (95% CI, 1337 to 32360 au; $p = 0.0347$) more total PlayerLoad and covered a higher total distance (MD, 162705.5 m; 95% CI, 21612.0 to 303799.0 m; $p = 0.0259$) within training. Significant differences were observed between the availability groups for all of the match exposure variables, with exception to sprint distance (MD, 1366.2 m; 95% CI, -825.4 to 3557.9 m; $p = 0.2083$) (Table 5.5).

Table 5.2. Structural validity of availability cluster groups.

Variables	**High availability** (n = 20)	**Low availability** (n = 5)	**Mean Difference**	**95% Confidence Interval**	[1] ***p*-value**	**Effect size (Cohen's *d*)**
Training availability (%)	96 ± 4	72 ± 17	24 ± 4	16 to 32	< 0.0001***	3.0
Match availability (%)	94 ± 5	63 ± 21	31 ± 5	21 to 42	< 0.0001***	3.1
Total availability (%)	96 ± 4	70 ± 18	26 ± 4	17 to 34	< 0.0001***	3.1

[1] All significant *p*-values are labelled accordingly: < 0.001 ***.

Table 5.3. Missed training sessions and matches during the season.

Missed training sessions & matches	**High availability (**n = 20)	**Low availability (**n = 5)
Missed training sessions	Median 7 (range, 0 to 21)	Median 32 (range, 26 to 96)
Missed matches	Median 4 (range, 0 to 9)	Median 18 (range, 12 to 46)
Missed total sessions	Median 11 (range 0 to 30)	Median 47 (range, 40 to 142)

Table 5.4. Injury location, type and severity within the low availability group.

	n
Injury location	
Hip	2
Knee flexor	1
Anterior thigh	1
Knee	1
Ankle	2
Foot	2
Injury type	
Muscle	3
Tendon	1
Ligament	2
Cartilage	3
Severity	
1 -3 days	1
8 – 28 days	1
> 28 days	7

Table 5.5. Differences of exposure variables (time-motion analyses) with respect to availability.

Time–motion variables	**High availability** (n = 17)	**Low availability** (n = 5)	**Mean Difference**	**95% Confidence Interval**	[1] ***p*-value**	**Effect size (Cohen's *d*)**
Training						
Total distance (m)	504847.0 ± 136673.8	342141.5 ± 116893.9	162705.5 ± 67640.0	21612.0 to 303799.0	0.0259*	1.2
High speed running (m)	15146.7 ± 1151.8	11992.4 ± 2123.8	3154.3 ± 2416.1	-1885.6 to 8194.1	0.2065	2.3
Total PlayerLoad (au)	52022 ± 3545	35173 ± 6536.8	16849 ± 7436	1337 to 32360	0.0347*	3.9
Number of sprints	872 ± 268	706 ± 309	167 ± 141	-127 to 460	0.2496	0.6
Sprint distance (m)	5032.7 ± 1898.3	4254.3 ± 1818.9	778.3 ± 95.8	-1219.7 to 2776.4	0.4260	0.4
Match						
Total distance (m)	286906.9 ± 66792.8	137009.1 ± 59320.6	149898.0 ± 33255.0	80529.0 to 219267.0	0.0002***	2.3
High speed running (m)	12234.6 ± 3883.1	6961.8 ± 5332.4	5272.9 ± 2143.4	801.9 to 9743.9	0.0231*	1.3
Explosive distance (m)	9222.1 ± 2012.8	5466.2 ± 3286.3	3755.9 ± 1182.3	1289.6 to 6222.2	0.0047**	1.6
Total PlayerLoad (au)	26316 ± 6628	12217 ± 4968	14099 ± 3221	7380 to 20817	0.0003***	2.2
Number of sprints	809 ± 63	456 ± 128	353 ± 146	50 to 657	0.0249*	4.4
Sprint distance (m)	4346.9 ± 1889.8	2980.7 ± 2624.5	1366.2 ± 1050.7	-825.4 to 3557.9	0.2083	0.7

[1] All significant *p*-values are labelled accordingly: < 0.05*, < 0.01** and < 0.001***.

From the availability groups, the frequency distributions regarding playing position were as follows: GK (high availability, n = 3; low availability, n = 0); FB (high, n = 1; low, n = 1); CB (high, n = 4; low, n = 1); CM (high, n = 6; low, n = 2); WG (high, n = 3; low, n = 1); and ST (high, n = 3; low, n = 0).

5.5.2 Baseline and change scores

From the pre-season testing, differences were shown between groups (Table 5.6). Participants with high availability had a lower sit and reach score at pre-season than those with low availability (MD, -9.8 cm; 95% CI, -16.9 to -2.8 cm; $p = 0.0091$). They also had a lower CMJ peak landing force asymmetry (MD, -14.86%; 95% CI, -29.14 to 0.57%; $p = 0.0422$). No differences in physical fitness development were found between high and low availability groups (Table 5.7).

Table 5.6. Pre-season baseline differences between availability groups. Continued on following page.

Variables	**High availability** (n = 20)	**Low availability** (n = 5)	**Mean Difference**	**95% Confidence Interval**	[1] ***p*-value**	**Effect size (Cohen's *d*)**
Age (years)	17.2 ± 0.73	17.1 ± 0.3	0.1 ± 0.3	-0.76 to 0.63	0.8506	0.1
Body mass (kg)	70.0 ± 6.4	64.6 ± 7.0	5.4 ± 3.3	-1.3 to 12.2	0.1091	0.8
Standing stature (cm)	176.7 ± 6.7	174.9 ± 6.6	1.8± 4.1	-6.8 to 10.5	0.6610	0.3
Seated stature (cm)	143.0 ± 3.3	141.0 ± 3.9	2.1 ± 2.1	-2.2 to 6.4	0.3194	0.6
Sit and reach (cm)	26.9 ± 7.4	36.7 ± 3.4	-9.8 ± 3.4	-16.9 to -2.8	0.0091**	1.4
CMJ: eccentric mean force (N)	696 ± 66	656 ± 71	40 ± 33	-29 to 109	0.2395	0.6
CMJ: jump height (cm)	34.2 ± 4.4	36.9 ± 4.7	-2.6 ± 2.2	-7.2 to 1.9	0.2437	0.6
CMJ: peak force (N)	3268 ± 364	3246 ± 526	22 ± 198	-388 to 432	0.9130	0.1
CMJ: concentric mean force asymmetry (%)	5.2 ± 5.1	7.8 ± 3.3	-2.6 ± 2.4	-7.6 to 2.5	0.3021	0.5
CMJ: eccentric mean force asymmetry (%)	8.9 ± 6.5	9.3 ± 8.3	-0.3 ± 3.4	-7.4 to 6.8	0.9244	0.0
CMJ: take off peak force asymmetry (%)	6.6 ± 5.1	9.0 ± 4.6	-2.4 ± 2.5	-7.6 to 2.8	0.3448	0.5
CMJ: peak landing force asymmetry (%)	15.4 ± 13.3	30.3 ± 16.1	-14.9 ± 6.9	-29.1 to 0.6	0.0422*	1.1

Table 5.6. Continued.

Variables	High availability (n = 20)	Low availability (n = 5)	Mean Difference	95% Confidence Interval	[1] *p*-value	Effect size (Cohen's *d*)
Nordic force (N)	378 ± 12	356 ± 44	23 ± 29	-38 to 83	0.4430	1.0
Nordic force imbalance (%)	9.1 ± 6.8	5.1 ± 1.4	3.9 ± 3.5	-3.3 to 11.3	0.2671	0.6
Adductor strength *via* GB 60^0 flexion (N)	352 ± 85	288 ± 67	64 ± 46	-32 to 161	0.1786	0.8
Adductor strength imbalance *via* GB 60^0 flexion (%)	4.5 ± 3.1	4.7 ± 2.3	-0.2 ± 1.7	-3.6 to 3.3	0.9301	0.1
Adductor strength *via* GB 90^0 flexion (N)	389 ± 96	365 ± 20	24 ± 44	-67 to 116	0.5891	0.3
Adductor strength imbalance *via* GB 90^0 flexion (%)	3.9 ± 3.0	3.3 ± 1.6	0.6 ± 1.4	-2.3 to 3.45	0.6664	0.2
Abductor strength mean force *via* GB 60^0 flexion (N)	306 ± 58	301 ± 70	5 ± 33	-64 to 75	0.8776	0.1
Abductor strength imbalance 60^0 flexion (%)	6.0 ± 4.9	2.9 ± 2.2	3.1 ± 2.5	-2.3 to 8.5	0.2393	0.7
Abductor strength force *via* GB 90^0 flexion (N)	291 ± 91	301 ± 70	-25 ± 47	-123 to 72	0.5935	0.1
Abductor strength imbalance *via* GB 90^0 flexion (%)	4.7 ± 3.7	3.9 ± 3.0	0.8 ± 2.0	-3.4 to 5.1	0.6951	0.3

[1] All significant *p*-values are labelled accordingly: < 0.05* and < 0.01**. Degrees (^{0}) of flexion for adductor and abductor strength refers to flexion of the hip. GB, GroinBar; CMJ, Counter movement jump.

Table 5.7. Differences of growth and physical fitness development with respect to availability. Continued on following page.

Change score variables	**High availability** (n = 20)	**Low availability** (n = 5)	**Mean Difference**	**95% Confidence Interval**	***p*-value**	**Effect size (Cohen's *d*)**
Body mass (kg)	4.4 ± 0.5	4.3 ± 2.3	0.1 ± 1.0	-2.0 to 2.3	0.8965	0.1
Standing stature (cm)	1.4 ± 0.7	1.6 ± 0.4	-0.2 ± 0.4	-1.0 to 0.7	0.6371	0.3
Seated stature (cm)	1.7 ± 0.8	1.4 ± 0.6	0.3 ± 0.5	-0.8 to 1.4	0.5620	0.4
Sit and reach (cm)	-0.5 ± 5.5	-2.9 ± 2.4	2.4 ± 2.5	-2.8 to 7.7	0.3499	0.5
CMJ: eccentric mean force (N)	30 ± 36	20 ± 10	10 ± 21	-34 to 54	0.6421	0.3
CMJ: jump height (cm)	3.8 ± 3.6	3.0 ± 2.8	0.8 ± 2.2	-3.8 to 5.3	0.7242	0.2
CMJ: peak force (N)§	3 ± 0	3 ± 0	0 ± 0	-1 to 1	0.9200	0.0
CMJ: concentric mean force asymmetry (%)	1.2 ± 8.6	-0.9 ± 7.5	2.2 ± 5.3	-8.9 to 13.2	0.6875	0.3
CMJ: eccentric mean force asymmetry (%)	-1.7 ± 8.2	0.7 ± 2.9	-1.2 ± 4.9	-11.3 to 9.0	0.8125	0.3
CMJ: take off peak force asymmetry (%)	0.9 ± 7.7	-4.1 ± 7.5	5.0 ± 4.8	-4.9 to 15.9	0.3077	0.7
CMJ: peak landing force asymmetry (%)	4.0 ± 25.3	-11.3 ± 6.0	15.3 ± 16.3	-18.8 to 49.3	0.3613	0.7
Nordic force (N)	26 ± 38	24 ± 35	2 ± 21	-43 to 46	0.9473	0.1

Table 5.7. Continued.

Change score variables	**High availability** (n = 20)	**Low availability** (n = 5)	**Mean Difference**	**95% Confidence Interval**	***p*-value**	**Effect size (Cohen's *d*)**
Nordic force imbalance (%)	-2.3 ± 8.9	1.0 ± 5.6	-3.6 ± 4.8	-13.7 to 6.6	0.4684	0.4
Adductor strength *via* GB 60^0 flexion (N)	10 ± 107	-5 ± 111	15 ± 70	-138 to 168	0.8364	0.1
Adductor strength imbalance *via* GB 60^0 flexion (%)	0.8 ± 0.4	7.5 ± 9.9	-7.2 ± 3.7	-15.1 to 0.1	0.0979	1.6
Adductor strength *via* GB 90^0 flexion (N)	7 ± 74	-48 ± 63	55 ± 42	-37 to 146	0.2195	0.8
Adductor strength imbalance *via* GB 90^0 flexion (%)	1.5 ± 4.2	3.8 ± 5	-2.3 ± 2.6	-8 to 3.4	0.3912	0.5
Abductor strength mean force *via* GB 60^0 flexion (N)	44 ± 51	21 ± 20	23 ± 31	-45 to 90	0.4782	0.5
Abductor strength imbalance 60^0 flexion (%)	-0.7 ± 4.8	2.1 ± 2.4	-2.8 ± 2.9	-9.2 to 3.7	0.3677	0.6
Abductor strength mean force *via* GB 90^0 flexion (N)	-17 ± 42	-50 ± 33	33 ± 27	-28 to 93	0.2542	0.8
Abductor strength imbalance *via* GB 90^0 flexion (%)	1.8 ± 5.0	0.1 ± 2.9	1.7 ± 3.1	-5.3 to 8.6	0.6106	0.4

Degrees (^{0}) of flexion for adductor and abductor strength refers to flexion of the hip; § log transformed; sphy, Sphygmomanometer; GB, GroinBar; CMJ, counter movement jump.

5.5.3 Correlations between physical development and exposure variables

Means and SDs for exposure, growth and physical fitness baseline and development variables independent of the participants' availability, are displayed in Table 5.7 and 5.8 respectively. Participants' change scores were utilised for correlational analysis.

Table 5.8. Exposure variables independent of availability.

Variable	Totalled exposure
Training	
Total distance (m)	467868.5 ± 147327.7
High speed running (m)	14429.8 ± 4828.1
Total PlayerLoad (au)	48192 ± 15991
Number of sprints	835 ± 279
Sprint distance (m)	4856 ± 1868
Match	
Total distance (m)	252839 ± 90572
High speed running (m)	11036 ± 4692.5
Explosive distance (m)	8368.5 ± 2782.0
Total PlayerLoad (au)	23111 ± 8645
Number of sprints	729 ± 318
Sprint distance (m)	4036.4 ± 2098.9

Table 5.9. Baseline and development scores independent of availability.

Variables	Baseline (pre-season)	Development (Change scores)
Body mass (kg)	68.9 ± 6.8	4.4 ± 2.0
Standing stature (cm)	176.5 ± 6.5	1.4 ± 0.6
Seated stature (cm)	142.9 ± 3.2	1.6 ± 0.8
Sit and reach (cm)	28.9 ± 7.8	-1.0 ± 5.0
CMJ: eccentric mean force (N)	689 ± 67	29 ± 33
CMJ: jump height (cm)	34.8 ± 4.4	3.7 ± 3.4
CMJ: peak force (N)	3264 ± 389	3 ± 0§
CMJ: concentric mean force asymmetry (%)	5.70 ± 4.88	0.93 ± 8.34
CMJ: eccentric mean force asymmetry (%)	9.00 ± 6.73	-1.57 ± 7.66
CMJ: take off peak force asymmetry (%)	7.09 ± 4.99	0.23 ± 7.66
CMJ: peak landing force asymmetry (%)	18.38 ± 14.82	1.90 ± 26.19
Nordic force (N)	374 ± 52	25 ± 36
Nordic force imbalance (%)	8.4 ± 6.4	-1.8 ± 8.3
Adductor strength *via* GB 60^0 flexion (N)	340 ± 85	6 ± 104
Adductor strength imbalance *via* GB 60^0 flexion (%)	4.5 ± 2.9	2.2 ± 6.2
Adductor strength *via* GB 90^0 flexion (N)	384 ± 86	-9 ± 73
Adductor strength imbalance *via* GB 90^0 flexion (%)	3.7 ± 2.7	2.1 ± 4.4
Abductor strength mean force *via* GB 60^0 flexion (N)	305 ± 58	40 ± 47
Abductor strength imbalance 60^0 flexion (%)	5.4 ± 4.7	-0.1 ± 4.5
Abductor strength mean force *via* GB 90^0 flexion (N)	296 ± 82	-25 ± 42
Abductor strength imbalance *via* GB 90^0 flexion (%)	4.6 ± 3.5	1.4 ± 4.5

Degrees (^{0}) of flexion for adductor and abductor strength refers to flexion of the hip; § log transformed; sphy, Sphygmomanometer; GB, GroinBar; CMJ, counter movement jump.

Correlations observed within the components of growth, physical fitness and exposure variables allowed for variables to be removed which were similar in outcomes and had a very large or almost perfect association ($r \geq 0.70$). Also, relationships could be observed between the variables within each of the components. Correlations between all change scores for growth development, physical fitness development and exposure variables are displayed for growth, (Table 5.9), physical fitness, (Table 5.10) and exposure (Table 5.11).

None of the growth variables had an association ($r \geq 0.70$) (Table 5.9), therefore all variables were included for the final correlations.

Table 5.10. Pairwise correlations of growth development variables.

Variable comparison	Body mass (kg)	Standing stature (cm)	Seated stature (cm)
Body mass (kg)	n/a	0.31^	0.15
Standing stature (cm)	0.31^	n/a	0.52^^
Seated stature (cm)	0.15	0.52^^	n/a

^ correlation $\geq$ 0.30, ^^ correlation $\geq$ 0.50.

Correlations between the physical fitness measures were very large ($r = 0.70$) for adductor and abductor strength at 60^0 hip flexion. Very large associations were also found between adductor and abductor strength variables at 90^0 hip flexion and at 60^0 hip flexion ($r = 0.71$) (Table 5.10). Consequently, it was concluded that all adductor and abductor strength variables at 60^0 hip flexion would be removed from the final analysis due to the very large associations with variables at 90^0 hip flexion. All other physical fitness correlations were < 0.70 (see Appendix 2). There were also multiple associations between CMJ, NF, adductor, and abductor strength measures, for example, decreased asymmetry in CMJ peak landing force was largely associated with increased NF asymmetrical differences (r = -0.57, large; *p* = 0.0274).

Table 5.11. Pairwise correlations of adductor and abductor strength development (physical fitness).

Variable comparison	ADDUCTION STRENGTH				ABDUCTION STRENGTH			
	Mean force (MF) *via* GB 60^0 flexion (N)	Imbalance *via* GB 60^0 flexion (%)	MF *via* GB 90^0 flexion (N)	Imbalance *via* GB 90^0 flexion (%)	MF *via* GB 60^0 flexion (N)	Imbalance *via* GB 60^0 flexion (%)	MF *via* GB 90^0 flexion (N)	Imbalance *via* GB 90^0 flexion (%)
Adductor strength								
MF *via* GB 60^0 flexion (N)	n/a	-0.46^	0.65^^	-0.34	0.70^^^	-0.41^	0.71^^^	-0.06
Imbalance *via* GB 60^0 flexion (%)	-0.46^	n/a	-0.67^^	0.27	-0.26^	0.16	-0.31^	-0.02
MF *via* GB 90^0 flexion (N)	0.65^^	-0.67^^	n/a	-0.13	0.35^	-0.37^	0.60^^	0.21
Imbalance *via* GB 90^0 flexion (%)	-0.34	0.27	-0.13	n/a	-0.08	0.07	0.14	0.49^
Abductor strength								
MF *via* GB 60^0 flexion (N)	0.70^^^	-0.26	0.35^	-0.08	n/a	-0.47^	0.57^^	-0.30^
Imbalance 60^0 flexion (%)	-0.41^	0.16	-0.37^	0.07	-0.47^	n/a	-0.20	0.38^
MF *via* GB 90^0 flexion (N)	0.71^^^	-0.31^	0.60^^	0.14	0.57^	-0.20	n/a	0.51^^
Imbalance *via* GB 90^0 flexion (%)	-0.06	-0.02	0.21	0.49^	-0.30	0.38^	0.51^^	n/a

Degrees^0 of flexion for adductor and abductor strength refers to flexion of the hip; sphy, Sphygmomanometer; GB, GroinBar. ^ correlation $\geq$0.30; ^^ correlation $\geq$0.50; ^^^ correlation $\geq$0.70.

There were multiple, very large and almost perfect associations from exposure variables (range, r = 0.71 to r = 1.00). In combination, training total PlayerLoad and training HSR had very large and almost perfect associations with the majority of the other training exposure variables (range, r = 0.71 to r = 0.99). The same was shown with match total PlayerLoad, match HSR (range, r = 0.73 to r = 1.00). Therefore, all total PlayerLoad and HSR variables for training sessions and matches were included within the final correlations and the rest of the variables were removed. Notably, higher exposure in training and matches from variables of total PlayerLoad (r = 0.76, very large; $p < 0.0001$) and high-speed running (r = 0.74, very large; $p < 0.0001$) had very large associations (Table 5.11).

Table 5.12. Pairwise correlations of exposure variables. Continued on following page.

Variable comparison		**TRAINING**					**MATCH**					
		Total distance (m)	**High speed running (m)**	**Total PlayerLoad (au)**	Number of sprints	Sprint distance (m)	Total distance (m)	**High speed running (m)**	Explosive distance (m)	**Total PlayerLoad (au)**	Number of sprints	Sprint distance (m)
TRAINING	Total distance (m)	n/a	0.78^^^	0.97^^^	0.77^^^	0.60^^	0.76^^^	0.51^^	0.58^^	0.73^^^	0.50^^	0.31^
	High speed running (m)	0.78^^^	n/a	0.74^^^	0.99^^^	0.92^^^	0.50^^	0.74^^^	0.66^^	0.46^	0.74^^^	0.67^^
	Total PlayerLoad (au)	0.97^^^	0.74^^^	n/a	0.71^^^	0.55^^	0.74^^^	0.44^	0.54^^	0.76^^^	0.44^^	0.25
	Number of sprints	0.77^^^	0.99^^^	0.71^^^	n/a	0.91^^^	0.47^	0.75^^^	0.68^^	0.43^	0.76^^^	0.69^^
	Sprint distance (m)	0.60^^	0.92^^^	0.55^^	0.91^^^	n/a	0.33^	0.69^^	0.59^^	0.30^	0.69^^	0.77^^^

Table 5.12. Continued.

Variable comparison		TRAINING					MATCH					
		Total distance (m)	**High speed running (m)**	**Total PlayerLoad (au)**	Number of sprints	Sprint distance (m)	Total distance (m)	High speed running (m)	Explosive distance (m)	**Total PlayerLoad (au)**	Number of sprints	Sprint distance (m)
MATCH	Total distance (m)	0.76^^^	0.50^^	0.74^^^	0.47^	0.33^	n/a	0.63^^	0.79^^^	0.97^^^	0.62^^	0.37^
	High speed running (m)	0.51^^	0.74^^^	0.44^	0.75^^^	0.69^^	0.63^^	n/a	0.93^^^	0.57^^	1.00^^^	0.92^^^
	Explosive distance (m)	0.58^^	0.66^^	0.54^^	0.68^^	0.59^^	0.79^^^	0.93^^^	n/a	0.75^^^	0.92^^^	0.80^^^
	Total PlayerLoad (au)	0.73^^^	0.46^	0.76^^^	0.43^	0.30^	0.97^^^	0.57^^	0.75^^^	n/a	0.57^^	0.31^
	Number of sprints	0.50^^	0.74^^^	0.44^	0.76^^^	0.69^^	0.62^^	1.00^^^	0.92^^^	0.57^^	n/a	0.91^^^
	Sprint distance (m)	0.31^	0.67^^^	0.25	0.69^^	0.77^^^	0.37^	0.92^^^	0.80^^^	0.31^	0.91^^^	n/a

^ correlation $\geq$0.30; ^^ correlation $\geq$0.50; ^^^ correlation $\geq$0.70.

Details of how development and exposure variables were separated for final correlations and their anticipated relationship to each other is displayed within Figure 5.3. It was anticipated that growth development would affect physical fitness development, whereas training and match exposure would have an influence on growth and physical fitness and/or in turn, be affected by growth and fitness.

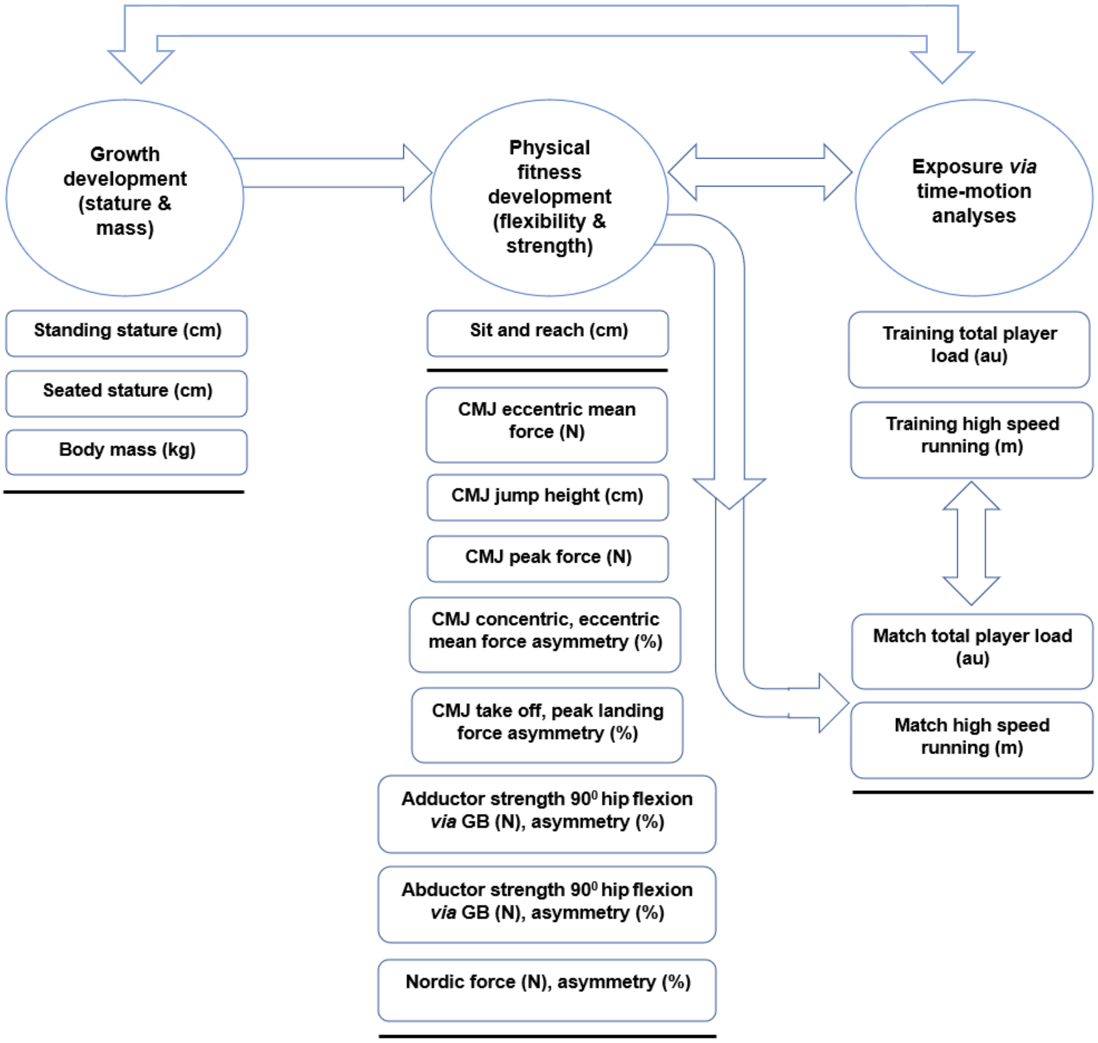

Figure 5.3. Conceptual framework for final analyses. The change scores throughout the season are grouped within the circles, these variables were selected following the data reduction process described earlier. Arrows indicate the predicted directional relationships of the grouped variables upon one another. Degrees (^{0}) of flexion for adductor and abductor strength refers to flexion of the hip adopted for testing. sphy, Sphygmomanometer; GB, GroinBar; CMJ, countermovement jump.

Correlations between the components of all of the change score variables (growth, physical fitness and exposure) across the season are reported in Appendix 2. Comparisons of correlations showed relationships between variables in different components.

Increases in growth were associated with increased NF. Increases in NF were associated with increased body mass (r = 0.48, moderate; *p* = 0.0455), standing stature (r = 0.46, moderate) and seated stature (r = 0.52, large; *p* = 0.0487). Increased seated stature was associated with increased CMJ eccentric mean force (r = 0.63, large; *p* = 0.0092) and asymmetry (r = 0.34, moderate), and abductor strength (90^0 flexion) (0.38, moderate). Increased body mass was also moderately associated with sit and reach scores (r = 0.49, moderate; *p* = 0.0143), and increased adductor strength (r = 0.31, moderate) and abductor imbalance (90^0 flexion) (r = 0.44, moderate).

The only relationship between growth and exposure was an increase in seated stature with greater match total PlayerLoad (r = 0.34, moderate). Changes in physical fitness carried over onto training and match exposure. Reduced CMJ eccentric mean force asymmetry was moderately associated with increased match (r = -0.48, moderate; *p* = 0.0370) and training (r = -0.46, moderate) HSR. Whereas increased CMJ take off peak force asymmetry was largely associated with greater match (r = 0.50, large; *p* = 0.00282) and training (r = 0.50, large; *p* = 0.0296) total PlayerLoad, training (r= 0.44) and match HSR. Greater improvements in CMJ jump height were largely associated with greater units of training total PlayerLoad (r = 0.62, large; *p* = 0.0043), moderately associated with greater HSR distances covered at training (r = 0.44, moderate) and greater units of match total PlayerLoad (r = 0.46, moderate; *p* = 0.048). Increases in CMJ peak force were largely associated with greater training total PlayerLoad (r = 0.52, large; *p* = 0.0235). Adductor and abductor strength at 90^0 hip flexion was associated with both training (r = 0.56 – 0.67) and match (r = 0.51) PlayerLoad.

5.5.4 Career progression

Only two participants from the cohort were successful in achieving first team standards. Both were in the high availability group and played in the CB positions. At the start of the season, they were taller (1.6 cm; 95% CI, 0.1 cm to 2.9 cm; $p = 0.0327$). They were also stronger, as evidenced by a greater CMJ jump height (1.8 cm; 95% CI, 0.4 to 3.1 cm; $p = 0.0134$), and mean NF (2 N; 95% CI, 0 to 3; $p = 0.0128$).

5.6 Discussion

It was anticipated that findings from the study would give insight into the impact that injury has on training and matches missed, development in growth and physical fitness and training and match exposure. It was also anticipated that the study would give details of measures, which could identify deficiencies in elite youth footballers at pre-season, that can result in reduced training and match availability. Finally, how variables of growth and physical development and exposure associate with each other and identify physical characteristics which predict attainment of elite senior football.

Reduced football exposure due to low availability could potentially inhibit development of academy footballers; with the precious time to progress in physical fitness and technical ability being lost (Ward *et al*., 2007). Injury occurrences make up a significant amount of reduced training and match availability in elite youth footballers (Read *et al*., 2018a and b). Injuries have economic impact, since there are financial costs to clubs for medical services involved in the diagnosis, treatment and rehabilitation processes and loss of return from an investment. Injuries can also impact team performance and disrupt practice sessions when key individual or multiple players are absent (Rossi *et al*., 2018). Although contact injuries are considered the most frequent cause of injury within elite youth football (Read *et al*., 2018a and b) they are hard to control, particularly in matches. In contrast, non-contact injuries are deemed controllable (McCall *et al*., 2014). In the present study, non-contact injuries accounted for a median of 9 (range, 0 to 96 training sessions) training sessions lost and a median of 6 (0 to 142 matches) matches missed for both injury groups. Clear differences were observed when players were categorised in high and low availability groups according to their levels of attendance at training sessions and matches. The low availability group missed significantly more total sessions across the EPPP season than the high availability group (high availability, Median 11 (range 0 to 30); low availability, Median 47 (range, 40 to 142)) confirming previous reports of the impact of any non-contact injury on lost playing time (Price *et al*., 2004; Read *et al*., 2018b). It would be expected that missing such a large number of sessions would have a significant impact on the playing development of these players (Ward *et al*., 2007).

TL can be described as an input variable, which can be controlled to produce an anticipated training response (Impellizzeri, Rampinini, and Marcora, 2005). However accumulated match loads play a significant part in academy footballers' total workloads (Bowen *et al*., 2017). Elite youth footballers must be able to adapt to, and tolerate, the physical requirements of increased loads placed on them to produce the desired physiological responses whilst mitigating injury risks. For this to be achieved players must keep their exposure levels consistent over a longitudinal period i.e., a playing season, to maintain and increase physical fitness and load workload tolerance (Bowen *et al*., 2017; Jeong *et al*., 2011). For example, detraining effects, from as little as two weeks absence from training, have been shown to lead to decreased performance in sprint velocity-based training (Rodríguez-Fernández *et al*., 2018). Therefore, players who are unable to complete intense running activity when injured for prolonged periods, are at a greater disadvantage since inactivity can reduce flexibility, cardio-vascular fitness and muscle glycogen levels, and physiological de-training effects are magnified with extended periods of inactivity (Mujika and Padilla, 2000). Additionally, detraining effects on eccentric strength, within a 4-week period of inactivity can be accelerated in athletes at an earlier stage in their development (Mujika and Padilla, 2000; Woods *et al*., 2004). In the present study, the players with high availability were exposed in training and matches to a higher total and covered a higher total distance, compared to those with low availability. Furthermore, within matches these same players also covered a greater cumulative HSR, explosive distance and sprints over the season. These findings are representative of the influence injury has on players missing opportunities to be exposed to running-based stimuli. Cardiovascular and metabolic de-training effects can be rapid during periods of inactivity in highly-trained athletes (Mujika and Padilla, 2000). These players' rehabilitation processes will have to focus on regaining physiological adaptations systematic for match demands and the high-volume of exposure associated with EPPP football (Read *et al*., 2018a and b). This requires gradual reintroduction to high chronic workloads and velocities, coupled with adequate regulated recovery, to mitigate injury reoccurrence (Bowen *et al*., 2017). Therefore, reintroduction to pitch-based activity could likely be challenging and timely for players with lengthy absence.

Despite the differences in training and match exposure, physical fitness development across the season was unaffected since no group differences were observed, which may suggest that the training exposure was sufficient. Research by Noon and colleagues (Noon *et al*., 2015), focused on EPPP academy players, who were the same age as in the present study. They suggested that stress recovery balances can have effects on physical fitness improvements across an EPPP season, even if training exposure is lowered. They also comment that the high training workload volume stipulated by the EPPP, was a factor for reduced physical development (Noon *et al*., 2015). Within the present study, both groups did not differ in pitch-based training exposure volume, with all participants, except for those rehabilitating, following EPPP category 1 requirements for the number of training sessions and training volume throughout the testing period. This supports the finding that there was no difference in the physical fitness change scores between availability groups.

Greater insights into the relationships between dose-response relationships with physical fitness and fatigue could identify how physiological fitness adaptations and fatigue change with respect to varying exercise doses to which academy players are exposed (Akubat, 2012). Impellizzeri and colleagues highlight through the Training Process model that training response outcomes from physiological adaptations are influenced primarily by internal TLs (Impellizzeri, Rampinini, and Marcora, 2005). The influence of individual characteristics, external TL (determined by organisation and quality and quantity) are also noted to affect internal TL. Therefore, just examining external exposure training processes in isolation are inappropriate, due to TLs being prescribed to teams rather than individuals, unless players are rehabilitating (Impellizzeri, Rampinini, and Marcora, 2005). This is important, as stress induced internal responses can vary between individual players when they complete the same training processes (Akubat, 2012; Impellizzeri, Rampinini, and Marcora, 2005).

GPS-based research is still in its infancy, but it is vitally important EPPP academies implement these methodologies because of their requirement within higher category academies, and to support player welfare and physical development (Bowen *et al*., 2017; Hewitt *et al*., 2014; Malone *et al*., 2017). If valid internal load measures and methods can be successfully employed by academies in combination with external load measures, this may provide for a greater understanding of training responses and improve performance outcomes and development and also help indicate player fatigue (Akubat *et* *al*., 2012; Akubat, 2012; Akubat *et al*., 2018; Impellizzeri, Rampinini, and Marcora, 2005). For example, the use of external: internal load ratios have been demonstrated to show critical relationships between measures of aerobic fitness and fatigue within footballers (Akubat, Barrett and Abt, 2014; Akubat *et al*., 2018). Combining individualised training impulse (iTRIMP) alongside exposure load variables of TD and HSR has shown that measuring external and internal loads in combination is limited within elite youth footballers. Accordingly, it would be insightful to examine load relationships to physical fitness (aerobic and strength) further in academy footballers (Akubat *et al*., 2018). It should also be considered, as identified within the present Study, that injured participants, if capable, were able to participate in strength and conditioning sessions during their rehabilitation processes. This could have reduced maladaptation and detraining processes and enable time for individual participants to focus on weaker physical movements and areas and maintain physical strength (Lepley *et al*., 2019; Reiman and Lorenz, 2011). It is also acknowledged that general concentric strength levels can be maintained within 4-weeks of inactivity (Mujika and Padilla, 2000).

From the pre-season fitness testing data, CMJ peak landing force was significantly more asymmetrical in the low availability group (MD, -14.86%; 95% CI, -29.14 to 0.57%; p = 0.0422). Landing mechanics have been highlighted previously as an injury ‘risk’ factor for footballers *via* mechanical loading of the knee and abnormal movement patterns, alongside neuromuscular imbalance such as activation patterns, lower limb, trunk and ligament dominance (Dai *et al*., 2014; Read *et al*., 2016). Significant neuromuscular imbalances, when coupled with a high subsequent force, could potentially result in ligament injury. For example, ankle ligament sprains are one of the most common in elite youth football (e.g., Price *et al*., 2004; Read *et al*., 2018a and b). Therefore, reducing neuromuscular imbalances *via* interventions, such as correcting limb dominance of the trunk and lower limbs and learning appropriate neuromuscular coordination when landing, would be considered beneficial to mitigate the ‘risk’ of injury. Learning appropriate neuromuscular co-ordination for landing within AFL U18 players has been shown to help alleviate potential injury risk (RR 0.72, 95% CI 0.52 to 0.98) (Scase *et al*., 2006). Though some of the landing mechanics may differ in football, this demonstrates that an intervention mitigating the risk of potential injury is possible. As discussed earlier the pre-season is a critical period to monitor ‘risks’ (e.g., Bradley and Portas, 2007). However, if a ‘risk’ factor such as landing asymmetry is highlighted, practitioners may have a limited window of time in which to ascertain the most appropriate intervention for an individual player as the pre-season period and September are characterised by high injury rates (e.g., Price *et al*., 2004).

The sit and reach test also discriminated between high and low availability groups at pre-season (MD, -9.8 cm; 95% CI, -16.9 to -2.8 cm; p = 0.0091). Reductions in muscular flexibility have been demonstrated to limit performance and increase muscle strain injury risk (Hatano *et al*., 2019; Witvrouw *et al*., 2003). Loss of extensibility in the hamstring muscles, which is examined by the sit and reach test, has been shown to provide a prediction of lower back pain and hamstring muscle strain injuries (Jones *et al.*, 2005). With the subsequent risk of flexibility, professional football clubs advocate the use of hamstring flexibility protocols (Dadebo, White and George, 2004; Hatano *et al*., 2019). Contrary to this previous research, greater mobility was observed in the low availability group suggesting that injury risk associated with flexibility may be more complex and resemble a ‘U’ shape in elite youth players, albeit the injuries may have different mechanisms. Previous research separated elite youth footballers (U15, U17, U19) into high and low flexibility groups by means of the sit and reach test. Players with low flexibility had < 22 cm (18 ± 5 cm) as a score and participants with high flexibility had a score > 28 cm (31.5 ± 3 cm) (Kirkini *et al.*, 2019). Low availability participants from the present study were considered to have excellent sit and reach scores (36.7 ± 3.4 cm) (range, 31.5 to 40.5 cm), the mean and max of their scores being much higher than in published data. This brings into question whether a sit and reach score can be high enough to warrant risk to injury, as characteristics of hypermobility could be demonstrated. The research here suggests that players who have significantly lower or higher flexibility could be at risk to injury. Hypermobility, affects multiple joints, resulting in ranges of motion in joints that exceed normal ranges (Russek, 1999). It is considered a risk factor to injury within elite youth and senior football (Konopinski *et al.*, 2016; Konopinski, Jones and Johnson, 2012; Le Gall *et al.*, 2006). Joint hypermobility has been demonstrated to be a risk factor for injury within elite senior English Premier League players (n = 54), with hypermobile players having higher injury occurrences (MD, 15.6; 95% CI 9.18 to 22.13 injuries/1,000 h; $p = 0.001$) and being expected to have an occurrence of one injury, a re-injury and a severe injury across a season, in comparison to non-hypermobile players (Konopinski *et al.*, 2016; Konopinski, Jones and Johnson, 2012). Hypermobility and other growth-related factors have been considered to influence the occurrence of increased training injuries within elite youth football (Le Gall *et al.*, 2006). Due to these findings, further examination into the interrelating factors of hypermobility and growth, and ranges of higher flexibility against injury risk within elite youth footballers would be interesting.

Multiple associations were found between training and match exposure GPS variables, in which there were very large associations between training and match (total PlayerLoad (r = 0.76; $p < 0.0001$), HSR (r = 0.74; $p < 0.0001$)). The multiple relationships demonstrated between training sessions and matches highlight whether greater training exposure stimuli could reflect greater match running performance, or whether academies should monitor a range of distances and movement velocities if they have strong correlations, i.e., training total distance with training total PlayerLoad (r = 0.97; almost perfect) and match HSR with match number of sprints (r = 1.00; almost perfect). As demonstrated in the present study and outlined in the literature, time-motion analyses have value in enabling training sessions to be designed to replicate and support match demands for individual players (Cummins *et al*., 2013). Furthermore, by implementing a repeated measures design, training and match loads can be examined in unison on a weekly basis giving greater determination that match demands are being reached within training sessions acutely through a season.

The influence that growth, physical development and exposure levels may have on one another has been reviewed previously within elite senior and youth footballers (Hammami *et al*., 2013; Di Mascio *et al*., 2020; Thorpe *et al*., 2017). Appraisal of the relationships found between groups of growth and physical fitness development, and exposure levels within the present study, indicate the possible influence which they may have on each another. These include the possible effect of growth on multiple physical fitness improvements (Stratton and Oliver, 2013). For example, within the present study, large associations between increases in seated stature and CMJ eccentric mean force were shown. By identifying associations between growth and physical fitness development, and associations between a range of physical fitness strength measures (present study), practitioners can review, when possible, to predict when performance improvements may occur, which thereby may help guide prescribed training for players. Greater NF within footballers has been attributed to body size (e.g., Buchheit *et al*., 2016; Markovic *et al*., 2020). Markovic and colleagues demonstrated that body size (body mass, standing stature) in U14 and U16 youth footballers is associated with age-related NF development. However, relative NF decreased within the U18 age group (Markovic *et al*., 2020). Within the present study, increased growth (body mass, standing and seated stature) was associated with increased mean NF. This suggests that eccentric knee flexor strength development could be a feature of metabolic adaptations attributed to growth (Armstrong, Barker and McManus, 2015) within U18 players. Therefore, it is important to monitor players' growth changes, irrespective of their age-group, when assessing NF development. Differing from previous findings (Faude *et al.*, 2011; Malone *et al.*, 2015a), CMJ jump height was associated with both training and match exposure (training total PlayerLoad (r = 0.62; large; *p* = 0.0043), training HSR (r = 44; moderate) and match total PlayerLoad (r = 0.46; moderate; *p* = 0.048), leading to the conclusion that improved vertical jump strength led to improved on-field movement exposure, or *vice versa*. Malone and colleagues indicated that tracking CMJ responses in greater detail over a longitudinal period with exposure, would be of benefit (Malone *et al.*, 2015a). The present study gives evidence that exposure levels and CMJ development could possibly influence each other over a season. This suggests that greater exposure could equal greater neuromuscular adaptation applicable for eccentric and concentric phases of vertical jump performance or *vice versa*. These adaptations are extended to asymmetrical differences between limbs from vertical jumping. Reduced CMJ eccentric asymmetry could aid HSR in matches. However, when players are exposed to greater PlayerLoads their take off peak force limb imbalances could be increased. Building on these findings the position-dependency of these measures' correlations could be scrutinised further (Buchheit *et al.*, 2010a). Unique findings were show between adductor and abductor strength at 90^0 hip flexion with both training and match PlayerLoad. This illustrates that hip and groin strength development, could enable players to tolerate greater pitch-based exposure or *vice versa*. These are important considerations as adductor strength development is influenced by match congestion for youth footballers (Wollin *et al.*, 2018). Future work could examine how optimum stimuli can be prescribed to either maintain or develop player's hip and groin strength, dependent on their stipulated running workloads.

Career progression was reviewed against the physical fitness variables within the study. The links between physical characteristics in elite youth footballers' performance, ability and career progression, and gaining playing contracts has been explored before (Deprez *et al*., 2015; Strauss, Jacobs and Van den Berg, 2012). Comparisons between elite and non-elite youth footballers have shown differences in physical performance, with elite youth players having greater change of direction and aerobic performance (Strauss, Jacobs and Van den Berg, 2012). Also, contracted players demonstrated greater horizontal jump and shorter sprinting capabilities than non-contracted players (Deprez *et al*., 2015). In the present study, participants who were selected earlier in their careers for elite senior first team football were taller (1.6 cm; 95% CI, 0.1 cm to 2.9 cm; $p = 0.0327$). and stronger (CMJ (1.8 cm; 95% CI, 0.4 to 3.1 cm; $p = 0.0134$), NF (2 N; 95% CI, 0 to 3; $p = 0.0128$)) and had a high attendance for training and matches. However, it has been noted that categorisation for youth players (i.e., elite, amateur) is not always uniform and therefore consideration should be given when comparing research findings from academy set-ups in different countries (Deprez *et al*., 2015). Additionally, standard progressions may differ between academy set-ups. This highlights that monitoring of physical characteristics in potential senior first team players, through ranges of physical fitness and stature characteristics is valuable information. While it is important not to disregard players who have not developed physically, or to prioritise solely on physical characteristics at a development age (Patel *et al*., 2019). Further research could examine ranges of physical characteristics applicable to the attainment of first team status. This could determine whether players are ready in their development to be introduced to an elite senior environment.

The present Study incorporated a range of physiological measures, monitoring components of growth, physical fitness strength and flexibility and pitch-based exposure. It was found that differences between availability groups at pre-season, indicated future low availability, but no differences in scores were identified between groups' physical development. The mechanisms of injury risk leading to inhibition of a player's development are multifactorial and extend beyond a physiological viewpoint requiring interdisciplinary methodology (Williams and Andersen, 2007). For example, it is possible for academies to monitor for injury risk using psychological measures to examine internal responses, within such an interdisciplinary approach (Johnson and Ivarsson, 2011). Recently, psychological characteristics have been examined in elite youth players, with the variances between the category standard of the EPPP (Saward *et al*., 2020). To build on from Study 2, Study 3 will investigate physiological and psychological measures in unison to examine the differences with playing availability due to injury and development in elite youth footballers. This examination will provide for a novel addition to the literature.

5.6.1 Limitations

There are recognised limitations within this current study. It was restricted to a cohort of EPPP youth academy football players from one professional organisation, which should be acknowledged when relating to different athletic groups. The conclusions should be viewed with caution because of the small sample size involved. As such the statistical approach used on such a small sample set cannot be used to inform practical recommendations at this stage. It is acknowledged that the study is exploratory in nature and is therefore an observational starting point for further study with larger cohorts, instead as conclusive. Also, the exploratory nature meant that *t*-tests were conducted without Bonferonni corrections to account for type 1 error. Though these corrections have been considered within some research examinations based on much higher numbers, application of such a correction would have been detrimental in the present project, as determination of significance would be difficult due to multiple measures being examined. Some of the fitness measures conducted in Study 1 which examined different mechanisms other than flexibility and strength such as sprint performance and change of direction, could not be replicated within the present study. Internal load measures were not included alongside the external load measures. This was because the internal load measures could not be completed repeatedly and reliably due to testing complications across the entire testing period. Full details of the limitations are discussed in Chapter 7.

5.6.2 Conclusions

Non-contact injuries impact an EPPP academy footballer’s availability through a season resulting in a significant loss of training and match exposure. While this may not impact on their physical development, exposure to competition is essential for developing psychological, tactical and technical skills not measured or assessed in this study. Protecting EPPP academy youth footballers from injury would be beneficial to the player and to the club’s investment. Multiple physical fitness measures can be used to assess injury risk. Flexibility may need to be evaluated further to highlight potential hypermobile characteristics in players, not just flexibility impairment, as well as neuromuscular control when landing. There are multiple relationships between growth and physical fitness development and exposure. Growth development is correlated with physical fitness changes, notably increases in NF with increased growth. This demonstrates that body size should be scrutinised within academies when observing eccentric knee flexor strength, as

NF improvements could be a feature of increased growth. Physical fitness development was correlated with training and match exposure measures. Of note, improved neurological adaptations conducive to vertical jump performance and hip and groin strength could help facilitate greater exposure to total PlayerLoad and high speed-running variables in both training sessions and matches. Thus, indicating the importance of an appropriate stimulus to help facilitate physiological adaptations and running performance. Introduction of physical fitness testing over a longitudinal period within an EPPP academy environment should therefore be helpful. Monitoring fitness more regularly could provide staff with up-to-date data to ensure they are better informed and proactive decisions are made with regard to player’s strength and conditioning provision. Additionally, growth and physical fitness measures, with a particular focus on stature and strength levels, could help highlight physical characteristics in players who are ready to participate in an elite senior first-team earlier in their careers than others.

Chapter 6: Study 3

An exploratory examination of psychological and physical factors to support the development of elite academy footballers

6.1 Abstract

Objectives. To assess the impact of reduced availability due to non-contact injury on players' physical and psychological development. To identify potential risk factors at the start of the pre-season and competitive season which could lead to reduced availability. To examine, independent of injury, relationships between physical and psychological development.

Design. A longitudinal observational study comparing availability groups and multiple physical and psychological measures across a pre-season and competitive EPPP season.

Participants. Footballers (n = 25) from a single EPPP category 1 academy (15.9 to 18.2 years; stature 177 ± 8.3 cm; and body mass 70.5 ± 7.3 kg) from U18 squad.

Main outcome measures. The training sessions and matches missed due to non-contact injuries were recorded across the season. Growth and physical fitness monitoring measures were recorded at the first pre-season and competitive season test, and the last test of the competitive season. Psychological measures RST-PQ and Brief COPE were administered for the start of the competitive season and RESTQ-52 two days prior to the last game of each month throughout the season.

Results. Three availability groups were identified: high, low pre-season high competitive season and moderate. Change scores across the competitive season differentiated between the availability groups. In contrast to players with high availability, players with low availability within the competitive season were able to improve their CMJ eccentric mean force to a greater extent ($p = 0.0307$). However, their asymmetrical differences increased in CMJ take-off peak force ($p = 0.0237$). Players with moderate availability reported reduced Active Coping ($p = 0.0043$) and Positive Reframing ($p = 0.0120$) when compared to players with high availability. Players with low availability across the competitive season had significantly higher fluctuations of Total Stress and Recovery compared to players with high availability ($p = 0.0046$). Independent of injury, numerous correlations were observed within and between components of growth, physical fitness and psychological development across the season. Examples include: increases in NF imbalance related to improvement in CMJ jump height and NF, though impaired linear sprint performance. When body mass increased so did eccentric knee flexion strength and Defensive Fight ($p = 0.0332$). Personality, coping, stress and recovery variables correlated with numerous physical fitness measures.

Conclusions. These findings support the provision of monitoring of strength-based asymmetry alongside interventions to address the re-injury risk and sprint development. Developing player's coping resources during rehabilitation processes might alleviate higher intrinsic psychological stress levels, whilst facilitating physical fitness development. As changes in psychological states are highly likely within players who are at an unstable stage of their cognitive development it would make sense to examine psychological aspects to a greater extent than is currently employed. Not just to mitigate injury risk, but to protect player's wellbeing when rehabilitating and their physical development.

6.2 Introduction

Academy football is primarily focused on a player's technical, tactical, and physical development (Jones *et al.*, 2019). Conditioning footballers effectively is a key priority. Conceptually, this involves exposure to a broad spectrum of physical stimuli combined with sufficient recovery time to accommodate specific adaptations and improve physical fitness capacities. This can develop robustness and protect footballers, enabling them to withstand the competition and training demands of academy football, where they are expected to perform at a high standard (Bowen *et al*., 2017; Jeong *et al*., 2011). The pre-season period is considered crucial for all footballers to attain physical fitness capacities and a load tolerance to be able to cope with the upcoming competitive season (Bowen *et al*., 2017; Ekstrand *et al*., 2019; Jeong *et al*., 2011). As such, players are typically screened in the pre-season, with a particular focus on intrinsic injury risk factors from a battery of physical fitness assessments (e.g., Bourne *et al*., 2018; Bradley and Portas, 2007; Chalmers *et al*., 2018; Hughes *et al*., 2020; Kiesel, Plisky and Voight, 2007; Noon *et al*., 2015). Given this focus, it has been proposed that the traditional ~4 weeks scheduled for an academy football pre-season is too short to attain efficient physiological adaptations to cope within the competitive season, consequently creating greater injury risk (Ekstrand *et al*., 2019). This argument is supported by the higher injury rates associated within the pre-season period, or the early start of the competitive season (August and September) (Le Gall *et al*., 2006; Price *et al*., 2004; Read *et al*., 2018b; Woods *et al*., 2002). Therefore, an examination of the differences of the pre-season period against the remainder of the competitive season with regards to reductions of training and match availability affected by non-contact injury, would be insightful. Introducing screening measures at the start of both the pre-season and the competitive season can allow academy staff to determine if there are intrinsic risks to their players at periods of the season where players are at the highest risk to injury. Also, if measures are repeated at specific time points of the season such as at the end of the season, physical development changes of individual players, injured and not injured, can be monitored. To progress Studies 1 and 2, this next Study was designed to monitor the development of players across the pre-season and the following competitive season independently whilst also determining whether further injury risks can be identified at the end of the pre-season. In addition, Study 3 will consider a wide range of growth and physical fitness measures (majority employed within Study 2) affected by non-contact injury and the impact of psychological factors against player availability. This study necessitated a change in the participant cohort because of the progression of the participants through the age groups. Approximately half the individuals were consistent with Study 2 and additional participants were recruited; the total numbers remained at 25.

Assessments of physical fitness and load are considered important to examine within academy football environments. This is clearly evidenced by the inclusion of testing measures prescribed by the EPPP. Psychological factors could be given greater focus as heightened levels of stress and inadequate coping resources are indicated to increase injury risk in elite footballers (e.g., Johnson and Ivarsson, 2011; Ivarsson, Johnson and Podlog, 2013). It has been established that performance and development pressures increase in elite academy players as they get older and with higher playing standards (Saward *et al.*, 2020). Furthermore, as stated by Sarmento and colleagues, there is a lack of research into the psychological factors that can influence an academy footballer's development (Sarmento *et al.*, 2018). Therefore, to help prevent injury risk and enable career progression, monitoring psychological factors and effectively applying appropriate interventions could be beneficial (Johnson and Ivarsson, 2011; Saward *et al.*, 2020). The stress-injury model proposed by Williams and Andersen (2007) (Figure 6.1) provides a framework for examining the impact of psychological factors on injury risk. The model hypothesises that a history of stressors, personality characteristics and insufficient coping resources can result in an athlete experiencing intensified stress levels with greater physiological activation and health disruptions. Stress reactivity of 'at risk' individuals leading to an adverse stress response is deemed to be a mechanism for heightened injury risk (Williams and Andersen, 1998). The model has been examined using elite footballers, within the Swedish Premier League (Ivarsson, Johnson and Podlog, 2013). Ivarsson and colleagues demonstrated that trait anxiety, negative-life-event stress, and daily hassles were significant indicators of injury occurrence (Ivarsson, Johnson and Podlog, 2013). The psychosocial recovery–stress state of players has been applied within multiple studies focusing on elite footballers (Brink *et al*., 2010; Ivarsson Johnson and Podlog, 2013; Laux *et al*., 2015). Brink and colleagues monitored stress and recovery in elite Dutch youth footballers to gain insight into the prevention of injuries and illness (Brink *et al*., 2010). Information about physical stress and injuries was determined daily and the psychosocial stress-recovery state of the players monthly, using the Recovery-Stress Questionnaire for Athletes (RESTQ-52-Sport, Dutch version). From the RESTQ-52, the researchers found a relationship between the subscale of Fitness/Injury and Injury Occurrence (traumatic and overuse injuries) (Brink *et al*., 2010); also, that General Stress and recovery states were related to illness occurrence (Brink *et al*., 2010). Similar to other studies focussing on elite youth and senior footballers (e.g., Ivarsson Johnson and Podlog, 2013; Laux *et al*., 2015), these findings demonstrated a link between injury occurrence, leading to a loss in training and match availability, and psychological factors (Brink *et al*., 2010). To the author's knowledge there is no research examining the influence of psychological factors on injury occurrence within U18 age group EPPP footballers. The U18 age group is at a higher injury risk compared to other age groups (Read *et al.,* 2018a and b; Renshaw and Goodwin, 2016; Tears, Chesterton and Wijnbergen, 2018). Due to the crucial stage of their football development, it might be anticipated that these players would be exposed to a large combination of physical and psychological stressors (Noon *et al*., 2015; Read *et al*., 2018a, Swainston, Wilson and

Jones, 2020). Incorporation of physical and psychological measures within an interdisciplinary approach could increase the likelihood of academies highlighting injury risks to players from such stressors. This would also indicate whether time lost to train and compete because of injury would affect physical and psychological changes in individual players, leaving them at further risk to injury or affecting their psychological well-being. The interdisciplinary approach used here represents a progression from the previous studies and any findings would provide a novel addition to the literature.

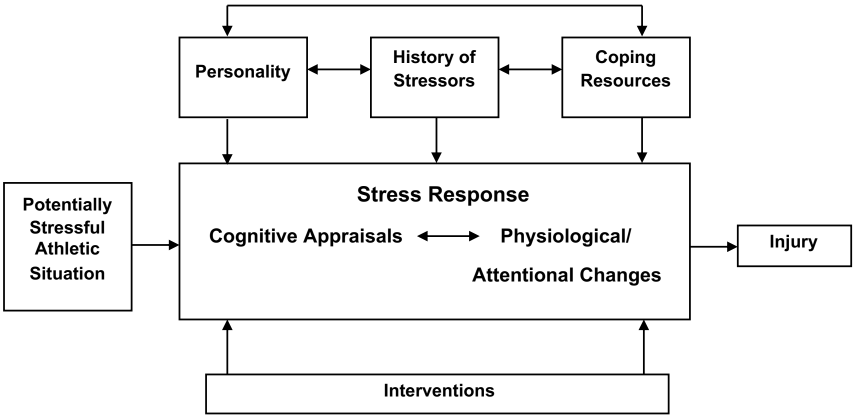

Figure 6.1. Revised version of the stress and injury model. (Taken from Williams and Andersen, 2007).

The main aims of this study were as follows: first, to explore the impact of reduced availability for training sessions and matches due to non-contact injury occurrences, on physical and psychological development. Second, to determine whether physical and psychological measures can indicate subsequent availability. Finally, to examine the relationships between physical and psychological development, independent of availability.

6.3 Methods

6.3.1 Participants

Participants were male elite academy football players from the same category 1 academy engaged in the full-time EPPP programme. All 25 participants were from the U18 age group squad, aged from 15.9 to 18.2 years, stature 177 ± 8.3 cm, and body mass 70.5 ± 7.3 kg. They were contracted to the club on a full-time scholarship and/or had a professional contract and were medically cleared to play at the start of the season on the basis of a cardiac and medical screening by the club. Specific criteria outlined below determined each participant's inclusion. All participants, where age appropriate, provided written consent or assent, and their parents or guardians provided written consent prior to the start of testing (Appendix 1). Ethical approval for the study was obtained from the University of South Wales Ethics Committee (ethics code: 17JSMW0701).

6.3.2 Inclusion criteria

These were fixed; to be included, participants were required to be full time contracted footballers to the U18 age group squad during the 2018/19 EPPP competitive season and had to be contracted to the Academy before the commencement of pre-season training. They were required have their injury details and all training and matches (total number) recorded.

6.3.3 Design and procedure

The study was a longitudinal observational study. All testing sessions took place at the same training ground venue. The study spanned 10 months from the start of pre-season until the end of the competitive 2018/19 EPPP season (July 2018 - April 2019). Availability due to the influence of non-contact injury was collected throughout the pre-season and the competitive season respectively. Growth and physical fitness measures were obtained at the time of the participant's first tests of the pre-season and the competitive season phases and their last test at the end of the competitive season. Testing sessions for growth and physical fitness measures were conducted prior to, or alongside the participants' athletic development sessions (prior to pitch-based training) within the weekly build up to matches**.** Participants were declared physically capable of performing any physical test and pitch-based training and matches prior to each testing session by the medical staff at the club. In all physical testing procedures, if the participant's scores indicated an issue, or they highlighted discomfort verbally prior, during, or afterwards, they were directed to the organisation's medical staff on duty and were reviewed to determine the appropriate treatment. All participants were familiar with, and had, completed all of the physical testing procedures before the study commenced. The Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ) (Corr and Cooper, 2016) and Brief COPE (Carver, 1997) were administered at the end of the pre-season period, to serve as the baseline score for the competitive season, and at the end of the competitive season. The Recovery-Stress Questionnaire for Athletes **(**RESTQ-52) (Kellmann and Kallus, 2001) was administered two days before the last match at the end of every month within both the pre-season (baseline score for the competitive season), and competitive season (Laux *et al*., 2015). Availability and all of the physical variables included within the study are displayed within Table 6.1. All of the sub-scales from the psychological measures included within the study are listed within Table 6.2. Figure 6.2 shows the timeline of data collection of the measures included and the time points at which the change scores were calculated.

Table 6.1. Availability, growth and physical fitness measures included within the study separated into components

Availability (training & matches)	Growth (anthropometric) screening variables	Physical fitness screening variables
PS missed training sessions	Body mass (kg)	Sit and reach (cm)
PS missed matches	Standing stature (cm)	Df lunge Left and Right (cm)
CS missed training sessions	Seated stature (cm)	Df lunge asym (%)
CS missed matches		CMJ: conc mf (N)
PS training availability (%)		CMJ: ecc mf (N)
PS match availability (%)		CMJ: jump height (cm)
CS training availability (%)		CMJ: pf (N)
CS match availability (%)		CMJ: conc mf asym (%)
		CMJ: ecc mf asym (%)
		CMJ: take off pf asym (%)
		CMJ: landing pf asym (%)
		Add strength (45^0 flexion) *via* sphy (mmHg)
		Mean NF (N)
		NF imbalance (%)
		5 m linear sprint (s)
		20 m linear sprint (s)
		30 m linear sprint (s)
		505-agility Left and Right (s)

PS, pre-season; CS, competitive season. Df, dorsiflexion; asym, asymmetry; Add, adductor; degrees (^{0}) of flexion for adductor strength refers to flexion of the hip; sphy, sphygmomanometer; CMJ, counter movement jump; NF, Nordic force; conc, concentric; ecc, eccentric; mf, mean force; pf, peak force.

Table 6.2. **Psychological measures and sub-scales included within the study.**

Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ) totalled sub-scales	**Recovery-Stress Questionnaire for Athletes (RESTQ-52) totalled sub-scales**	**Brief COPE totalled sub-scales**
Behavioural Approach System Factors (BAS): Reward Interest, Goal-Drive Persistence, Reward Reactivity, Impulsivity Fight-Flight-Freeze System (FFFS) Behavioural Inhibition System (BIS) Defensive Fight (DF)	General Stress scales: General Stress, Emotional Stress, Social Stress, Conflicts/ Pressure, Fatigue, Lack of Energy, Somatic Complaints Sport Specific Stress scales: Disturbed Breaks, Burnout/ Emotional Exhaustion, Fitness/ Injury General Recovery scales: Success, Social Relaxation, Social Relaxation, General Well-Being and Sleep Quality Sport Specific Recovery: Fitness/ Being in Shape, Burnout/ Personal Accomplishment, Self-Efficacy and Self-Regulation.	Self-Distraction Active Coping Denial Substance Use Use of Emotional Support Use of Instrumental Support Behavioural Disengagement Venting Positive Reframing Planning Humour Acceptance Religion Self-Blame

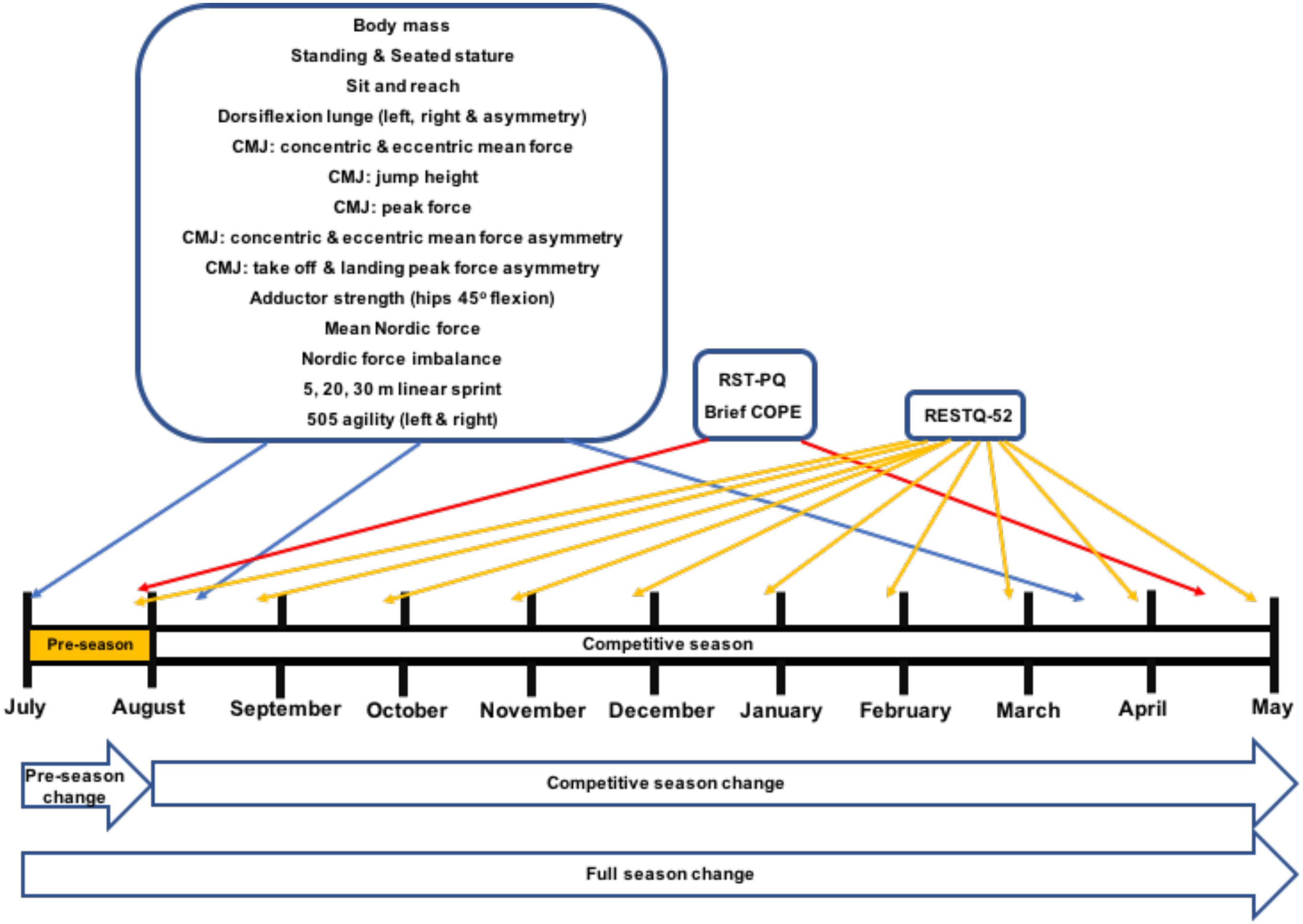
Body mass
Standing & Seated stature
Sit and reach
Dorsiflexion lunge (left, right & asymmetry)
CMJ: concentric & eccentric mean force
CMJ: jump height
CMJ: peak force
CMJ: concentric & eccentric mean force asymmetry
CMJ: take off & landing peak force asymmetry
Adductor strength (hips 45° flexion)
Mean Nordic force
Nordic force imbalance
5, 20, 30 m linear sprint
505 agility (left & right)
RST-PQ
Brief COPE
RESTQ-52
Pre-season
Competitive season
July
August
September
October
November
December
January
February
March
April
May
Pre-season change
Competitive season change
Full season change

Figure 6.2. Timeline of physical and psychological measures included within the study. CMJ, counter movement jump; RST-PQ, Reinforcement Sensitivity Theory of Personality Questionnaire; RESTQ-52, Recovery-Stress Questionnaire for Athletes. Thick white arrows show the period over which change scores were calculated across the pre-season, competitive season and full season respectively. Coloured arrows (yellow, red and blue) indicate the time point at which physical and psychological measures were collected.

6.3.4 Training and match availability

Participants' injury and playing details were collected prior to each training session and match throughout the season from U18 squad daily medical reports generated by the club's medical staff. The investigator was present for each session and communicated regularly with the medical staff, ensuring that there were no errors in collection data for the study (Wik *et al*., 2019). These details were categorised according to whether the participant had sustained any non-impact (contact) injury resulting in them not being able to participate in any capacity with pitch-based (training and match) activity (excluding the day of injury) (Price *et al*., 2004). In addition, all pitch-based training sessions and matches across the season were recorded.

6.3.5 Participant details

Participant details comprised of age and playing position. Age was recorded in years. Playing position was assigned by the participants' most predominant playing position through the season. Positions were separated into GK, FB, CB, CM, WG and ST.

6.3.6 Growth and physical fitness measures

Anthropometric measures: body mass and standing and seated stature, and physical fitness measures: sit and reach, dorsiflexion lunge, CMJ *via* force platforms, adductor strength *via* syphgmomanometer, NF, linear sprint performance (5, 20, 30 m sprints) and change of direction (505-agility) were collected. Protocols and reliability for these measures are described previously (Chapters 3, 4 and 5).

6.3.7 Psychological measures

Each psychological measure included in the study represented a key psychological factor from Williams and Andersen's model of stress and injury (2007) (Figure 6.1). The psychological measures assessed personality: RST-PQ, history of stressors: RESTQ-52 and coping resources: Brief COPE (Appendix 3). Each questionnaire was completed individually in the presence of the researcher. Details and reliability for these measures are described in Chapters 3. All the sub-scales for the RST-PQ and the Brief COPE were included for analysis (Table 6.2). For the RST-PQ, the four Behavioural Approach System Factors (BAS) scales were examined together and an additional scale, Defensive fight (DF,) was included. For the RESTQ-52, the subscales General Recovery, General Stress, Sport Specific Stress and Sport Specific Stress were included alongside calculated Global Stress, Global Recovery, and Total Stress and Recovery scores.

6.4 Statistical analyses

Statistical analyses were completed using JMP v 15.0 Pro Statistical Discovery Software (SAS Institute, Inc, Cart, North Carolina USA). Descriptive statistics were reported for all variables. Data are displayed as the median (range), Chi Square (χ^2) with probability value (*p*) or (*p*) in isolation, unless indicated otherwise. Significance was set at $p < 0.05$ for all analyses. A flow-chart outlining the statistical analyses is displayed within Appendix 2.

Availability was calculated as a percentage for training and matches during: (i) the pre-season period and, (ii) the competitive season. Ward's hierarchical cluster analysis was used to categorise participants into groups based on their availability profiles. Three groups were identified, and classifications were confirmed, using a dendrogram, constellation and parallel plot. To confirm the structural validity of the availability cluster groups, Kruskal-Wallis tests and *post hoc* comparisons using the Wilcoxon method where appropriate were performed between training and match availability.

The frequency distributions of the three availability groups were found in relation to playing position. Age was calculated by years from the date of birth to the first day of the pre-season (testing period). All of the change scores across the pre-season, competitive season and the full season were calculated respectively for all of the physical measures. The pre-season change score was calculated as: start of competitive season score minus start of pre-season score; competitive season change score as: end of season score minus start of competitive season score; and full season change scores as: end of season score minus start of pre-season score. From the physical fitness measures, improvements would show a positive score with exceptions of imbalance (asymmetry) (%), the 5, 20 and 30 m sprints (s) and 505-agility (s), where a negative score would reflect an improvement. Additionally, the change scores for the psychological measures RST-PQ and Brief COPE were calculated, which involved subtracting the participant's last score of the competitive season away from their baseline score.

Non-parametric statistical tests were utilised within the analysis due to the use of three availability groups (High availability, n = 12; High pre-season, low competitive season availability, n = 7; Moderate availability, n = 6; Table 6.3) and the non-normal distributions of a number of variables. Kruskal-Wallis tests and if appropriate, *post hoc* comparisons using the Wilcoxon method were completed to compare age, growth and physical fitness measures between the three availability groups at the start of the pre-season and the competitive season and the change scores across these periods, respectively. Subsequently, employing the same statistical tests, differences between groups for the RST-PQ and Brief COPE were examined for measures completed at the end of the pre-season and the change scores across the competitive season. For the RESTQ-52 measure, mean scores and coefficient of variation (CV) across the competitive season were calculated. The mean score represented how the participants felt on average over the competitive season and how the CV fluctuated. Significant differences in mean scores and CV among availability groups were then examined using the same non-parametric statistical tests as described above.

Relationships within and between growth, physical fitness and psychological development variables could be observed by performing a correlational analysis of the change scores. These were calculated from the first (baseline) and last test of both the physical and psychological measures, and CV (RESTQ-52 only) across the competitive season. As there were a large number of dependent variables included within the study (total n of physical variables, n = 23; psychological variables, n = 25) a process of data reduction was followed to avoid potential multicollinearity. This ensured that variables measuring the same outcomes (mechanisms) could not potentially be repeated within correlations. The variables were grouped into the following components: 1. Growth development; 2. Physical fitness development and 3. Psychological changes (personality, coping) and fluctuations (stress and recovery). Spearman's ρ correlation coefficient analyses were performed within the components (growth, physical fitness, psychological variables) to establish the significance of relationships between each of the variables. Growth and physical fitness variables which measured the same specific mechanisms i.e., linear sprint speed, were compared against each other. If two variables assessed the same specific mechanism and were found to have a significant correlation between each other ($p < 0.05$), the most commonly used variable with respect to reports in the literature was retained for analysis. Due to the investigation being exploratory in nature and the possible relationships between the psychological measures being novel within the participant cohort, none of the psychological variables were removed. Following data reduction, final Spearman's ρ coefficients between the psychological and remaining growth, physical fitness variables' change scores, and fluctuations were determined to identify correlations that were significant ($p < 0.05$).

6.5 Results

6.5.1 Impact of reduced training and match availability

From hierarchical cluster analysis of the 25 participants' training and match availability during the pre-season and competitive season, three groups were classified with the following characteristics: high availability in both the pre-season and the competitive season (high availability) (n = 12); high availability during the pre-season and low availability during the competitive season (high pre-season, low competitive season availability) (n = 7) and moderate availability across both the pre-season and competitive season (moderate availability) (n = 6) (Figure 6.3).

Structural validity of the availability groups was confirmed by group differences in all training and match availability data within the pre-season and the competitive season (Table 6.3). Analysis confirms the following results: pre-season training availability ($\chi^2 = 21.221$, $p = 0.001$), competitive season training availability ($\chi^2 = 14.22$, $p = 0.0008$), match training availability ($\chi^2 = 20.226$, $p = 0.001$), and match availability ($\chi^2 = 14.26$, $p = 0.0008$) (Table 6.3). *Post hoc* analysis demonstrated significant differences between each of the availability groups ($p < 0.0001$ to $p = 0.0336$). The missed training sessions and matches across the pre-season and competitive season for each availability group are displayed in Table 6.4.

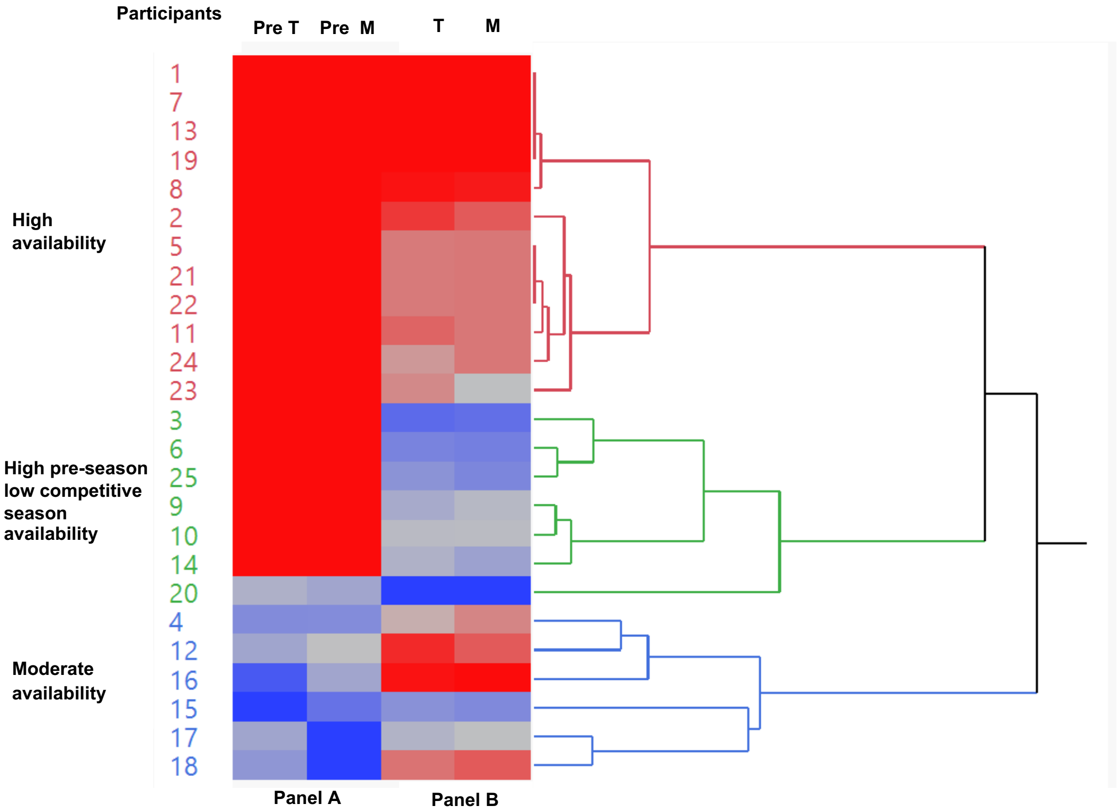

Figure 6.3. Hierarchical clustering dendrogram, separating availability injury groups for training sessions and matches. Identification for individual participants is listed on the left-hand side of the figure. The colours indicate group membership: High availability (red numbers), High pre-season and low competitive season availability (green numbers), Moderate availability (blue numbers). Panel A: Pre-season availability. Panel B: competitive season availability. Colours represent: red high availability (red shading)/ low availability (blue shading). Columns marked Pre-T and T (pre-training and competitive season training availability respectively); columns marked Pre-M and M (match availability during the re-season and competitive season respectively).

Table 6.3. Structural validity of availability cluster groups.

Variables	HA (n = 12)	HPS, LCSA (n = 7)	MA (n = 6)	Chi Square (χ^2)	^{1}*p*-value
PSTA (%)	100 (100)	100 (87 to 100)	76 (48 to 83)	21.221	0.0001***
CSTA (%)	91 (81 to 100)	49 (0 to 72)	82 (48 to 99)	14.22	0.0008**
PSMA (%)	100 (100)	100 (80 to 100)	65 (40 to 90)	20.226	0.0001***
CSMA (%)	87 (74 to 100)	41 (0 to 72)	86 (43 to 100)	14.26	0.0008**
FSTA (%)	92 (84 to 100)	55 (12 to 76)	81 (48 to 94)	15.1247	0.0005**

HA, high availability; HPS, LCSA high pre-season, low competitive season availability; MA, moderate availability; PSTA, pre-season training availability; CSTA, competitive season training availability; PSMA, pre-season match availability; CSMA, competitive season match availability; FSTA, full season training availability. ^{1} All significant *p*-values are labelled accordingly: < 0.01 **, < 0.001 ***.

Table 6.4. Missed pre-season and competitive season training sessions and matches due to non-contact injury, according to availability group.

Missed T & M	**HA** (n = 12)	**HPS, LCSA** (n = 7)	**MA** (n = 6)
PST	0 (0)	0 (0)	6 (4 to12)
CST	14 (0 to 29)	79 (44 to 156)	28 (1 to 81)
PSM	0 (0)	0 (0 to 2)	4 (1 to 6)
CSM	6 (0 to 12)	27 (13 to 46)	7 (0 to 26)

T & M, training sessions and matches; HA, high availability; HPS, LCSA high pre-season, low competitive season availability; MA, moderate availability; PST, pre-season training; CST, competitive season training; PSM, pre-season match; CSM, competitive season match.

For each availability group, the distributions of position are displayed in Figure 6.4.

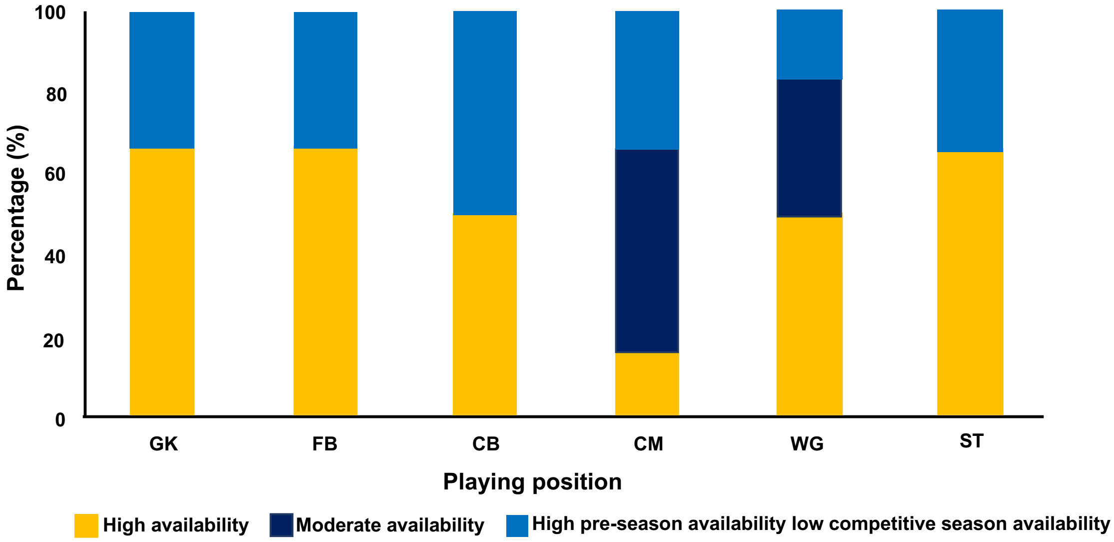

Figure 6.4. Percentage of players in different availability groups according to playing position. GK, goalkeeper; FB, fullback; CB, centre back; CM, central midfielder; WG, winger; ST, striker. Availability groups: attendance at training and matches across the pre-season and competitive season due to the influence of non-contact injury separated by colour scheme (yellow, dark blue, light blue).

6.5.2 Availability group differences for physical measures at the start of the pre-season and the change scores across the pre-season

There were no differences between the availability groups in age and scores for growth and physical fitness measures at the start of the pre-season (Table 6.5). From Kruskal-Wallis tests only 505-agility (Left) scores showed an initial significance between the availability groups ($\chi^2 = 6.0375$, $p = 0.0489$). However, no significance was found between the availability groups from a *post-hoc* test ($p = 0.0518$ to 01326). Across the pre-season period growth and physical fitness change scores did not differ between availability groups (Table 6.6).

Table 6.5. Physical scores at the start of the pre-season, dependent on availability. Continued on next page.

Variables	**HA** (n = 12)	**HPS, LCSA** (n = 7)	**MA** (n = 6)	**Chi Square** (χ^2)	^{1} ***p*-value**
Age (years)	16.8 (15.9 to 17.7)	17.3 (16.3 to 18.2)	17.3 (16.4 to 18.1)	1.8503	0.3965
Body mass (kg)	71.5 (58.5 to 82.5)	73.6 (51.1 to 81.4)	68.2 (66.5 to 74.5)	0.6367	0.7273
Standing stature (cm)	175.9 (163.4 to 188.6)	182.1 (153.2 to 187.2)	179.8 (171.6 to 189.5)	0.3918	0.8221
Seated stature (cm)	144.7 (138.4 to 150.3)	146.1 (135.2 to 147.1)	143.6 (142.1 to 148.0)	0.7145	0.6996
Sit and reach (cm)	26.0 (21.5 to 32.0)	34.0 (23.0 to 43.0)	32.0 (43.0 to 44.5)	5.8322	0.0541
Df lunge Left (cm)	11.0 (7.5 to 17.0)	13.0 (10.5 to 15.5)	14.5 (10.5 to 15.0)	3.0440	0.2183
Df lunge Right (cm)	11.0 (8.5 to 17.0)	13.0 (11.5 to 16.0)	15.0 (12.0 to 15.5)	4.1347	0.1265
Df lunge asym (%)	6.4 (0.0 to 22.0)	10.5 (0.0 to 39.0)	7.0 (0.0 to 15.8)	0.1717	0.9177
CMJ: conc mf (N)	1293 (1130 to 1441)	1454 (1061 to 1625)	1205 (1104 to 1584)	3.1682	0.2051
CMJ: ecc mf (N)	697 (585 to 904)	701 (492 to 788)	660 (647 to 739)	0.5967	0.7420
CMJ: jump height (cm)	35.2 (30.7 to 42.7)	40.1 (31.1 to 41.0)	36.8 (27.3 to 38.7)	3.1420	0.2078

Table 6.5. Continued.

Variables	**HA** (n = 12)	**HPS, LCSA** (n = 7)	**MA** (n = 6)	**Chi Square** (χ^2)	**^{1}*p*-value**
CMJ: pf (N)	3249 (2371 to 4448)	3772 (2665 to 4491)	3119 (2861 to 4129)	4.2180	0.1214
CMJ: conc mf asym (%)	4.6 (0.7 to 15.1)	1.8 (0 to 10.5)	7.3 (1.8 to 10.7)	4.4306	0.1091
CMJ: ecc mf asym (%)	5.2 (0.6 to 11.3)	7.9 (0.5 to 13.8)	9.5 (0.8 to 27.6)	0.9398	0.6251
CMJ: take off pf asym (%)	3.8 (1.7 to 24.5)	2.4 (1.5 to 5.0)	8.8 (4.7 to 13.7)	5.9161	0.0519
CMJ: landing pf asym (%)	12.8 (0.8 to 26.1)	13.7 (4.2 to 23.8)	6.2 (0.3 to 25.6)	1.1531	0.5618
Add strength (45^0 flexion) (mmHg)	120 (90 to 175)	130 (90 to 205)	135 (120 to 170)	0.9519	0.6213
Mean NF (N)	453 (367 to 497)	435 (264 to 537)	376 (331 to 480)	1.2277	0.5413
NF imbalance (%)	15.9 (5.6 to 22.2)	7.3 (0.0 to 28.4)	11.2 (0.7 to 17.3)	2.8491	0.2406
5 m linear sprint (s)	1.00 (0.92 to 1.12)	0.99 (0.92 to 1.03)	1.02 (0.92 to 1.07)	1.5947	0.4505
20 m linear sprint (s)	3.03 (2.85 to 3.18)	2.96 (2.84 to 3.04)	3.01 (2.80 to 3.09)	2.8641	0.2388
30 m linear sprint (s)	4.24 (3.94 to 4.43)	4.14 (3.98 to 4.22)	4.17 (3.89 to 4.33)	2.0762	0.3541
505-agility Right (s)	2.51 (2.33 to 2.69)	2.49 (2.46 to 2.73)	2.59 (2.44 to 2.62)	0.9648	0.6173
505-agility Left (s)	2.51 (2.35 to 2.70)	2.55 (2.52 to 2.60)	2.60 (2.55 to 2.61)	6.0375	0.0489*

HA, high availability; HPS, LCSA high pre-season, low competitive season availability; MA, moderate availability; Df, dorsiflexion; asym, asymmetry; Add, adductor; degrees (^{0}) of flexion for adductor strength refers to flexion of the hip; CMJ, counter movement jump; NF, Nordic force; conc, concentric; ecc, eccentric; mf, mean force; pf, peak force. **^{1}** All significant *p*-values are labelled accordingly: ≤ 0.05*.

Table 6.6. Physical development scores across the pre-season, dependent on availability. Continued on next page.

Variables	**HA** (n = 12)	**HPS, LCA** (n = 7)	**MA** (n = 6)	**Chi Square** (χ^2)	[1] ***p*-value**
Body mass (kg)	-1.4 (-3.3 to 1.5)	0.4 (-2.8 to 1.2)	0.6 (-1.5 to 1.9)	4.0369	0.1329
Standing stature (cm)	0.2 (0 to 0.9)	0.4 (0 to 1.5)	0.4 (0 to 0.6)	1.0185	0.6009
Seated stature (cm)	0.5 (0.0 to 1.6)	0.8 (0.1 to 1.2)	0.0 (0.0 to 1.0)	4.2665	0.1185
Sit and reach (cm)	0.5 (-2.0 to 8.5)	-2.5 (-5.0 to 1.0)	-2.0 (-4.0 to 6.5)	5.8400	0.0539
Df lunge Left (cm)	-0.5 (-1.0 to 3.0)	0.0 (-5.0 to 0.5)	-1.0 (-2.0 to 1.5)	0.2777	0.8074
Df lunge Right (cm)	0.0 (-2.5 to 1.0)	-1.0 (-4.0 to -0.5)	-1.0 (-4.0 to 1.0)	5.4441	0.0657
Df lunge asym (%)	0.0 (-22.0 to 15.0)	0.0 (-39.0 to 19.5)	0.0 (-3.8 to 15.0)	0.3139	0.8548
CMJ: conc mf (N)	-29 (-91 to 122)	-13 (-129 to 102)	14 (-62 to 137)	0.6873	0.7092
CMJ: ecc mf (N)	-7 (-116 to 69)	0 (-12 to 40)	5 (-6 to 9)	0.9414	0.6246
CMJ: jump height (cm)	-1.6 (-5.3 to 2.6)	0.0 (-3.6 to 4.0)	1.4 (-2.4 to 5.1)	3.6445	0.1617
CMJ: pf (N)	-148 (-1007 to 1478)	-117 (-456 to 965)	-81 (-325 to 198)	0.4138	0.8131
CMJ: conc mf asym (%)	1.2 (-6.9 to 12.6)	0.4 (-5.0 to 5.2)	-4.5 (-53 to 4.4)	2.2614	0.3228
CMJ: ecc mf asym (%)	3.2 (-6.7 to 10.0)	-2.3 (-6.3 to 8)	-0.9 (-19.6 to 9.6)	1.8335	0.3998

Table 6.6. Continued.

Variables	**HA** (n = 12)	**HPS, LCA** (n = 7)	**MA** (n = 6)	**Chi Square** (χ^2)	^{1}***p*-value**
CMJ: take off pf asym (%)	1.4 (-9.3 to 13.8)	-1.1 (-3.7 to 2.2)	-3.5 (-4.9 to 4.5)	3.7691	0.5119
CMJ: landing pf asym (%)	-0.3 (-9.6 to 17.7)	-4.4 (-10.1 to 6.1)	1 (-9.7 to 8.6)	1.6385	0.4408
Add strength (45^0 flexion) (mmHg)	7.5 (-20 to 70)	15 (-40 to 50)	0 (-60 to 65)	0.6774	0.7127
Mean NF (N)	-13 (-77 to 16)	-54 (-165 to 37)	-10 (-27 to 0)	2.8294	0.2430
NF imbalance (%)	-3.5 (-1.8 to 1.1)	-4.7 (-1.5 to 2.3)	-4.1 (-9.3 to 1.3)	0.1162	0.9436
5 m linear sprint (s)	-0.04 (-0.12 to 0.14)	0.01 (-0.08 to 0.16)	0.01 (-0.12 to 0.04)	0.1763	0.9156
20 m linear sprint (s)	-0.05 (-0.14 to 0.09)	-0.02 (-0.05 to 0.09)	-0.06 (-0.08 to 0.14)	1.9774	0.3721
30 m linear sprint (s)	-0.06 (-0.13 to 0.10)	-0.04 (-0.16 to 0)	-0.03 (-0.03 to -0.14)	0.0353	0.9825
505-agility Right (s)	-0.13 (-0.25 to 0.04)	-0.08 (-0.32 to -0.04)	-0.23 (-0.29 to -0.16)	1.4341	0.4882
505-agility Left (s)	-0.12 (-0.27 to 0.12)	-0.19 (-0.21 to -0.14)	-0.17 (-0.2 to -0.13)	1.2746	0.5287

HA, high availability; HPS, LCSA high pre-season, low competitive season availability; MA, moderate availability; Df, dorsiflexion; asym, asymmetry; Add, adductor; degrees Nordic force; conc, concentric; ecc, eccentric; mf, mean force; pf, peak force.

6.5.3 Availability group differences for physical measures at the start of the competitive season and the change scores across the competitive season

No significant differences were observed between the availability groups at the start of the competitive season for the physical measures (Table 6.7). However, across the competitive season group differences were demonstrated in physical fitness development for CMJ eccentric mean force ($\chi^2 = 6.484$, $p = 0.0391$) and take off peak force asymmetry ($\chi^2 = 8.1758$, $p = 0.0168$) (Table 6.8). *Post hoc* analysis observing these CMJ variables demonstrated that players who had low availability across the competitive season were able to increase their eccentric mean force to a greater extent than players with high availability ($p = 0.0237$). Furthermore, low availability players' asymmetrical differences between lower limbs were increased for take-off peak force, whilst players with high availability were able to reduce their asymmetry differences ($p = 0.0307$).

Table 6.7. Physical scores at the start of the competitive season, dependent on availability. Continued on following page.

Variables	**HA** (n = 12)	**HPS, LCSA** (n = 7)	**MA** (n = 6)	**Chi Square** (χ^2)	[1] ***p*-value**
Body mass (kg)	70.0 (57.0 to 79.5)	74.7 (51.1 to 78.6)	68.7 (65.7 to 75.3)	0.4629	0.7934
Standing stature (cm)	176.4 (164.1 to 189.5)	182.5 (154.1 to 187.2)	180.4 (172.2 to 189.5)	0.5521	0.7588
Seated stature (cm)	145.4 (139.1 to 150.7)	146.8 (136.4 to 148.1)	144.1 (142.1 to 148.0)	0.7190	0.6980
Sit and reach (cm)	27.0 (23.0 to 34.5)	33.0 (18.0 to 43.0)	32.5 (11.0 to 42.0)	4.1345	0.1265
Df lunge Left (cm)	11.0 (7.5 to 17.0)	13.0 (5.5 to 13.5)	12.5 (12.0 to 15.0)	3.0908	0.2132
Df lunge Right (cm)	11.0 (9.0 to 17.0)	12.5 (10.0 to 13.5)	13.5 (11.0 to 15.0)	4.6027	0.1001
Df lunge asym (%)	0.0 (0.0 to 32.0)	11.5 (0 to 24.8)	12.0 (0.0 to 25.0)	0.9790	0.6129
CMJ: conc mf (N)	1319 (1101 to 1585)	1400 (1019 to 1644)	1240 (1203 to 1522)	2.2034	0.3323
CMJ: ecc mf (N)	693 (571 to 788)	734 (500 to 778)	665 (648 to 741)	0.6819	0.7111
CMJ: jump height (cm)	35.2 (29.7 to 45.3)	37.4 (31.9 to 44.1)	34.7 (28.7 to 43.8)	3.5154	0.1724
CMJ: pf (N)	3352 (2480.8 to 4351)	3799 (2549 to 4393)	3077 (2781 to 3804)	4.2669	0.1184
CMJ: conc mf asym (%)	5.8 (1.4 to 16.7)	3.2 (0.6 to 7.0)	3.6 (0.8 to 6.7)	3.0684	0.2156
CMJ: ecc mf asym (%)	6.4 (2.0 to 14.3)	3.2 (1.6 to 11.5)	8.0 (5.1 to 10.4)	2.1447	0.3422

Table 6.7. Continued.

Variables	**HA** (n = 12)	**HPS, LCSA** (n = 7)	**MA** (n = 6)	**Chi Square** (χ^2)	[1]***p*-value**
CMJ: take off pf asym (%)	5.6 (1.8 to 21.5)	2.3 (0.7 to 5.6)	4.7 (0.7 to 13.3)	5.2338	0.0730
CMJ: landing pf asym (%)	14 (0.1 to 29.2)	13.2 (1.9 to 19.8)	8.9 (0.5 to 18.0)	1.0091	0.6038
Add strength (45^0 flexion) (mmHg)	140 (95 to 200)	120 (100 to 220)	140 (60 to 200)	0.0187	0.9907
Mean NF (N)	393 (328 to 496)	409 (271 to 432)	423 (331 to 453)	1.3010	0.5218
NF imbalance (%)	15.9 (5.6 to 22.2)	7.3 (0.0 to 28.4)	11.2 (0.7 to 17.3)	0.9494	0.6221
5 m linear sprint (s)	0.98 (0.92 to 1.11)	0.98 (0.92 to 1.08)	0.96 (0.91 to 1.02)	0.9493	0.6221
20 m linear sprint (s)	3.00 (2.81 to 3.04)	3.00 (2.81 to 3.05)	2.95 (2.94 to 3.01)	0.0099	0.9950
30 m linear sprint (s)	4.17 (3.93 to 4.30)	4.1 (3.87 to 4.19)	4.16 (3.98 to 4.19)	0.7245	06961
505-agility Right (s)	2.4 (2.27 to 2.52)	2.41 (2.38 to 2.47)	2.46 (2.29 to 2.52)	0.4405	0.8023
505-agility Left (s)	2.37 (2.27 to 2.64)	2.37 (2.31 to 2.41)	2.42 (2.41 to 2.46)	2.8563	0.2398

HA, high availability; HPS, LCSA high pre-season, low competitive season availability; MA, moderate availability; Df, dorsiflexion; asym, asymmetry; Add, adductor; degrees (^{0}) of flexion for adductor strength refers to flexion of the hip; CMJ, counter movement jump; NF, Nordic force; conc, concentric; ecc, eccentric; mf, mean force; pf, peak force. [1] All significant *p*-values are labelled accordingly: ≤ 0.05*.

Table 6.8. Physical development scores across the competitive season, dependent on availability. Continued on next page.

Variables	**HA** (n = 12)	**HPS, LCA** (n = 7)	**MA** (n = 6)	**Chi Square** (χ^2)	[1] ***p*-value**
Body mass (kg)	2.9 (-11.4 to 5.0)	3.0 (-0.3 to 4.7)	2.5 (1.6 to 4.0)	0.3055	0.8583
Standing stature (cm)	1.1 (0.2 to 1.9)	0.9 (0.3 to 2.3)	0.6 (0.1 to 1.7)	1.5739	0.4552
Seated stature (cm)	0.5 (0.0 to 1.4)	0.4 (0.3 to 1.1)	0.5 (0.0 to 1.5)	0.0577	0.9716
Sit and reach (cm)	-3.5 (-11.5 to 2.0)	-3.0 (-21.5 to 9.0)	-1.0 (-16.0 to 3.0)	0.4608	0.7942
Df lunge Left (cm)	0.0 (-2.5 to 1.0)	0.5 (-1.0 to 3.0)	0.5 (-2.5 to 3.0)	3.6807	0.1588
Df lunge Right (cm)	0.0 (-4.5 to 1.5)	0.5 (-1.5 to 2.0)	1.0 (-2.5 to 5.5)	1.5109	0.4698
Df lunge asym (%)	4.7 (-24.7 to 49.0)	0.0 (-7.0 to 13.0)	2.0 (-25 to 37.5)	1.5809	0.4536
CMJ: conc mf (N)	119 (-47 to 232)	120 (6 to 369)	179 (30 to 217)	1.0662	0.5868
CMJ: ecc mf (N)	11 (17 to 67)	37 (14 to 47)	38 (27 to 46)	6.4840	0.0391*
CMJ: jump height (cm)	6.0 (-0.8 to 8.6)	4.2 (1.5 to 6.6)	4.1 (3.0 to 7.6)	0.6853	0.7099
CMJ: pf (N)	396 (54 to 715)	290 (-197 to 893)	428 (422 to 1099)	1.6615	0.4357
CMJ: conc mf asym (%)	-0.6 (-10.2 to 10.8)	1.8 (-0.8 to 10.8)	5 (-2.6 to 8.6)	2.8152	0.2447
CMJ: ecc mf asym (%)	4.4 (-13.3 to 21.8)	9.4 (4.4 to 19.5)	7.2 (-2.7 to 11.0)	3.4650	0.1768

Table 6.8. Continued.

Variables	**HA** (n = 12)	**HPS, LCA** (n = 7)	**MA** (n = 6)	**Chi Square** (χ^2)	[1] ***p*-value**
CMJ: take off pf asym (%)	-0.9 (-13.3 to 8.4)	4.9 (1.1 to 14.4)	-0.8 (-11.7 to 12.9)	8.1758	0.0168*
CMJ: landing pf asym (%)	-5.8 (-22.2 to 15.0)	-0.7 (-10.9 to 10.9)	-5.8 (-14.2 to -1.7)	2.3818	0.3039
Add strength (45^0 flexion) (mmHg)	40 (-35 to 85)	5 (-20 to 80)	38 (0 to 120)	2.4525	0.2934
Mean NF (N)	40 (9 to 176)	142 (85 to 178)	90 (59 to 12)	5.7500	0.0564
NF imbalance (%)	-2.3 (-18.3 to 9.2)	6.4 (-2.3 to 7.9)	7.2 (4.8 to 9.6)	3.3929	0.1833
5 m linear sprint (s)	-0.08 (-0.16 to 0.04)	0.03 (-0.19 to 0.06)	0.02 (0.00 to 0.04)	1.9094	0.3849
20 m linear sprint (s)	-0.07 (-0.15 to 0.03)	-0.06 (-0.20 to -0.02)	0.01 (-0.01 to 0.03)	2.5411	0.2807
30 m linear sprint (s)	-0.05 (-0.17 to 0.03)	-0.04 (-0.22 to -0.03)	0.02 (0.02)	2.7798	0.2491
505-agility Right (s)	0.04 (0.00 to 0.12)	0.06 (0.00 to 0.08)	0.03 (0.01 to 0.04)	0.5407	0.7631
505-agility Left (s)	0.10 (0.03 to 0.15)	0.10 (0.01 to 0.13)	0.06 (-0.01 to 0.13)	0.7361	0.6921

HA, high availability; HPS, LCSA high pre-season, low competitive season availability; MA, moderate availability; Df, dorsiflexion; asym, asymmetry; Add, adductor; degrees (^{0}) of flexion for adductor strength refers to flexion of the hip; CMJ, counter movement jump; NF, Nordic force; conc, concentric; ecc, eccentric; mf, mean force; pf, peak force. [1] All significant *p*-values are labelled accordingly: ≤ 0.05*.

6.5.4 Availability group differences for baseline and change scores from psychological measures

Scores (acting as a baseline for the competitive season) from psychological measures RST-PQ and the Brief COPE did not differ between availability groups (Appendix 2). Across the competitive season, no significant differences were observed in the change scores between the groups with any of the RST-PQ variables (Appendix 2). In contrast, significant group differences were observed for the Brief COPE variables. For Active Coping ($\chi^2 = 8.3305$, $p = 0.0155$), the moderate availability group recorded significantly lower scores than both the high availability group ($p = 0.0043$) and high pre-season/low competitive season group ($p = 0.0319$). For Positive Reframing ($\chi^2 = 7.6824$, $p = 0.0215$), the moderate availability group's scores were significantly lower than the high availability group's ($p = 0.0120$). Descriptive statistics of baseline and change scores across the competitive season for the RST-PQ and Brief COPE, are reported in Table 6.9; statistical results for each variable are reported in Appendix 2.

From the RESTQ-52 measure, no significant differences were observed between the groups for mean scores across the season; the same was true for all the CV scores. However, Total Stress and Recovery ($\chi^2 = 9.1980$, $p = 0.0101$) was significant. From *Post hoc* analysis, significant differences were shown between the high availability group and the group with low availability across the competitive season ($p = 0.0046$). This demonstrated that the low availability group had significantly higher fluctuations across the course of the competitive season (Table 6.10).

Table 6.9. Baseline and change scores of psychological personality and coping, dependent on availability.

	Baseline scores			**CS change scores**		
Variables	**HA** (n = 12)	**HPS, LCSA** (n = 7)	**MA** (n = 6)	**HA** (n = 12)	**HPS, LCA** (n = 7)	**MA** (n = 6)
RST-PQ						
Fight-Flight-Freeze System	22 (13 to 29)	23 (18 to 27)	23 (16 to 26)	1 (-4 to 11)	1 (-5 to 2)	0 (-7 to 4)
Behavioural Inhibition System	52 (30 to 84)	51 (37 to 70)	52 (31 to 58)	-1 (-20 to 16)	5 (-23 to 7)	3 (-11 to 10)
Behavioural Approach System	95 (79 to 109)	89 (77 to 102)	87 (75 to 104)	-3 (-18 to 12)	0 (-19 to 3)	2 (-11 to 11)
Defensive Fight	28 (24 to 31)	26 (19 to 29)	24 (17 to 32)	0 (-6 to 3)	-1 (-1 to 6)	5 (0 to 6)
Brief COPE						
Self-Distraction	5 (2 to 8)	5 (2 to 7)	5 (4 to 7)	0 (-1 to 2)	0 (-3 to 3)	0 (-1 to 1)
Active Coping	5 (3 to 7)	5 (4 to 7)	6 (4 to 6)	1 (0 to 4)	1 (-1 to 4)	-1 (-2 to 0)
Denial	3 (2 to 8)	2 (2 to 3)	2 (2 to 3)	0 -6 to 3)	1 (0 to 4)	0 (-1 to 2)
Substance Use	2 (2 to 8)	2 (2)	2 (2)	0 (-6 to 4)	0 (0 to 1)	0 (0)
Use of Emotional Support	4 (2 to 7)	4 (2 to 6)	5 (3 to 6)	1 (-2 to 3)	1 (-1 to 3)	-1 (-3 to 1)
Use of Instrumental Support	4 (2 to 7)	5 (4 to 8)	5 (3 to 6)	1 (-1 to 3)	0 (-1 to 4)	0 (-2 to 1)
Behavioural Disengagement	3 (2 to 8)	2 (2 to 3)	2 (2 to 3)	0 (-4 to 2)	1 (-1 to 5)	0 (-1 to 5)
Venting	5 (2 to 7)	3 (3 to 6)	4 (2 to 5)	1 (-3 to 3)	2 (-4 to 4)	1 (-2 to 3)
Positive Reframing	4 (2 to 7)	5 (3 to 7)	6 (3 to 6)	2 (-1 to 2)	0 (-1 to 2)	-1 (-4 to 0)
Planning	5 (2 to 7)	7 (4 to 8)	6 (3 to 7)	1 (-1 to 3)	1 (-4 to 3)	-1 (-3 to 1)
Humour	4 (2 to 7)	3 (2 to 5)	4 (4 to 5)	0 (-2 to 4)	0 (-2 to 5)	0 (-3 to 1)
Acceptance	5 (2 to 7)	4 (3 to 7)	5 (4 to 7)	1 (-2 to 3)	1 (-2 to 3)	0 (-1 to 2)
Religion	5 (2 to 8)	2 (2 to 8)	4 (2 to 7)	0 (-3 to 3)	0 (-3 to 3)	0 (-1 to 2)
Self-Blame	5 (2 to 8)	5 (5 to 7)	6 (4 to 8)	0 (-2 to 1)	-1 (-2 to 3)	(0 -4 to 2)

HA, high availability; HPS, LCSA high pre-season, low competitive season availability; MA, moderate availability.

Table 6.10. Comparisons of psychological stress and recovery across a season as a function of availability.

RESTQ-52 variables	**HA** (n = 12)	**HPS, LCSA** (n = 7)	**MA** (n = 6)	**Chi Square** (χ^2)	[1]*p*-**value**
Mean scores					
General Stress	2.2 (0.5 to 3.4)	2.2 (1.1 to 2.8)	2.3 (1.8 to 2.6)	1.068	0.9480
General Recovery	3.2 (2.5 to 4.5)	2.9 (1.8 to 3.7)	3.0 (2.3 to 3.8)	0.8595	0.6507
Sport Specific Stress	2.2 (0.7 to 3.5)	2.0 (1.3 to 2.7)	2.4 (2.2 to 2.7)	1.0859	0.5810
Sport Specific Recovery	3.4 (2.7 to 4.4)	3.2 (1.9 to 4.2)	3.2 (1.8 to 3.8)	1.1309	0.5681
Global Stress	2.7 (2.1 to 3.3)	2.4 (2.1 to 3.2)	2.6 (2.3 to 2.9)	1.5607	0.4583
Global Recovery	2.9 (2.1 to 3.3)	2.8 (2.0 to 3.1)	2.9 (2.1 to 3.1)	0.8745	0.6458
Total Stress and Recovery	2.8 (2.1 to 3.3)	2.6 (2.1 to 3.0)	2.7 (2.2 to 3.0)	0.8591	0.6508
Coefficient of variation %					
General Stress	20.2 (6.3 to 83.6)	35.5 (11.8 to 53.6)	17.0 (14.7 to 52.70	3.0811	0.2143
General Recovery	14 (7.4 to 27.5)	12.7 (2.3 to 23.7)	18.8 (8.0 to 22.9)	1.3068	0.5203
Sport Specific Stress	36.4 (1.6 to 150.5)	65.0 (23.8 to 69.7)	25.5 (11.2 to 59.5)	3.0442	0.2183
Sport Specific Recovery	12.0 (2.3 to 40.1)	27.5 (7.7 to 45.9)	18.7 (10.4 to 33.6)	2.9305	0.2310
Global Stress	19.0 (0.0 to 81.4)	15.6 (2.0 to 53.9)	12.3 (1.3 to 35.1)	0.6075	0.7381
Global Recovery	35.1 (7.8 to 104.9)	24.9 (6.8 to 73.0)	21.5 (3.4 to 39.4)	2.1152	0.3473
Total Stress and Recovery	1.3 (0.2 to 5.5)	5.6 (1.9 to 8.8)	3.5 (0.3 to 8.4)	9.1980	0.0101*

HA, high availability; HPS, LCSA high pre-season, low competitive season availability; MA, moderate availability; RESTQ-52, The Recovery-Stress Questionnaire for Athletes. [1] All significant *p*-values are labelled accordingly: ≤0.05*.

6.5.5 Correlations of physical and psychological variables

Medians and ranges for physical and psychological development variables independent of the participants' availability, are displayed in Table 6.12 and 6.13, respectively. Participants' change scores were utilised for correlational analysis for all variables, except for those from the RESTQ-52 measure where the CV was employed.

Table 6.11. Baseline and development scores from physical measures, independent of availability.

Variables	Baseline scores	Development (Change scores)
Body mass (kg)	70.7 (51.1 to 82.5)	2.4 (-13.7 to 5.1)
Standing stature (cm)	178.6 (153.2 to 189.5)	0.8 (0.1 to 2.3)
Seated stature (cm)	144.3 (135.2 to 150.3)	1.2 (0.0 to 2.3)
Sit and reach (cm)	29.0 (15.0 to 44.5)	-2.0 (-26 to 7.5)
Df lunge Left (cm)	13.0 (7.5 to 17.0)	-0.5 (-2.5 to 3.0)
Df lunge Right (cm)	13.0 (8.5 to 17.0)	-1.0 (-5.5 to 3.5)
Df lunge asym (%)	8.0 (0.0 to 39.0)	0.0 (-26.0 to 49.0)
CMJ: conc mf (N)	1298 (1061 to 1625)	98 (123 to 356)
CMJ: ecc mf (N)	683 (492 to 904)	29 (-133 to 80)
CMJ: jump height (cm)	36.5 (27.3 to 42.7)	3.8 (-2.0 to 9.0)
CMJ: pf (N)	3333 (2371 to 4491)	425 (-315 to 1531)
CMJ: conc mf asym (%)	4.1 (0 to 15.1)	1.8 (-3.9 to 10.6)
CMJ: ecc mf asym (%)	7.9 (0.5 to 27.6)	3.2 (-8.6 to 22.5)
CMJ: take off pf asym (%)	4.6 (1.5 to 24.5)	1.7 (-10.7 to 12.2)
CMJ: landing pf asym (%)	12.8 (0.3 to 26.1)	-4.2 (-23.9 to 25.2)
Add strength (45^0 flexion) *via* sphy (mmHg)	130 (90 to 205)	42.5 (-15 to 120)
Mean NF (N)	437 (264 to 537)	28 (-45 to 121)
NF imbalance (%)	12.4 (0.0 to 28.4)	-2.0 (-19.7 to 5.5)
5 m linear sprint (s)	1.00 (0.92 to 1.12)	-0.03 (-0.14 to 0.05)
20 m linear sprint (s)	3.00 (2.8 to 3.18)	-0.09 (-0.18 to 0.00)
30 m linear sprint (s)	4.18 (3.89 to 4.43)	-0.09 (-0.25 to 0.00)
505-agility Right (s)	2.51 (2.33 to 2.73)	-0.06 (-0.24 to 0.04)
505-agility Left (s)	2.55 (2.35 to 2.70)	-0.08 (-0.24 to 0.08)

Df, dorsiflexion; asym, asymmetry; Add, adductor; degrees (^{0}) of flexion for adductor strength refers to flexion of the hip; CMJ, counter movement jump; NF, Nordic force; Df, dorsiflexion; asym, asymmetry; Add, adductor; degrees (^{0}) of flexion for adductor strength refers to flexion of the hip; CMJ, counter movement jump; NF, Nordic force; conc, concentric; ecc, eccentric; mf, mean force; pf, peak force.

Table 6.12. Baseline and development scores from psychological measures, independent of availability.

Variables	Baseline scores	Development (Change scores)
RST-PQ		
Fight-Flight-Freeze System	23 (13 to 29)	1 (-7 to 11)
Behavioural Inhibition System	51 (30 to 84)	1 (-23 to 16)
Behavioural Approach System	91 (75 to 109)	0 (-19 to 12)
Defensive Fight	26 (17 to 32)	0 (-6 to 6)
Brief COPE		
Self-Distraction	5 (2 to 8)	0 (-3 to 3)
Active Coping	5 (3 to 7)	1 (-2 to 4)
Denial	2 (2 to 8)	0 (-6 to 4)
Substance Use	2 (2 to 8)	0 (-6 to 4)
Use of Emotional Support	4 (2 to 7)	1 (-3 to 3)
Use of Instrumental Support	4 (2 to 8)	1 (-2 to 4)
Behavioural Disengagement	2 (2 to 8)	0 (-4 to 5)
Venting	4 (2 to 7)	1.5 (-4 to 4)
Positive Reframing	5 (2 to 7)	1 (-4 to 2)
Planning	5 (2 to 8)	1 (-4 to 3)
Humour	4 (2 to 7)	0 (-3 to 5)
Acceptance	5 (2 to 7)	1 (-2 to 3)
Religion	3 (2 to 8)	0 (-3 to 3)
Self-Blame	5 (2 to 8)	0 (-4 to 3)
RESTQ-52: coefficient of		
General Stress	n/a	21.6 (6.3 to 83.6)
General Recovery	n/a	14.1 (2.3 to 27.5)
Sport Specific Stress	n/a	46.2 (1.6 to 150.5)
Sport Specific Recovery	n/a	15.0 (2.3 to 45 9)
Global Stress	n/a	16.5 (0.0 to 81.4)
Global Recovery	n/a	26.4 (3.4 to 104.9)
Total Stress and Recovery	n/a	2.7 (0.2 to 8.8)

RST-PQ, The Reinforcement sensitivity theory of personality questionnaire; RESTQ-52, The Recovery-Stress Questionnaire for Athletes.

6.5.5.1 Data reduction: Physical variables

Correlations observed within the components of growth and physical fitness highlighted relationships between the variables. From analysis, established multicollinearity guided the removal of physical variables involving similar mechanisms from the significance of their correlations. Spearman's ρ correlation coefficient between all change scores for growth and physical fitness development are displayed within the following Tables: growth Table 6.12; physical fitness Table 6.13.

Within the growth variables standing and seated stature were significantly correlated ($p = 0.0365$), therefore seated stature was not included in the between-component analysis (Table 6.12). Significant correlations (ranging from $p < 0.0001$ to $p = 0.05$) were found between the physical fitness development measures (Table 6.13). Of note, improved strength development was correlated with improved change of direction performance i.e., when CMJ concentric mean force ($p = 0.05$) and jump height ($p = 0.0013$) improved, 505-agility times also improved. Interestingly, when NF imbalance increased so did CMJ jump height, mean NF and 20 m sprint times (Table 6.13). Post review, the following variables were included for the final analysis: Dorsiflexion lunge (left and right), sit and reach, CMJ jump height, CMJ concentric and eccentric mean force and asymmetry, CMJ take off and peak landing force asymmetry, mean NF and NF imbalance, Adductor strength (hips 45^0 flexion), 505-agility (left and right) and 30 m linear sprint. These selected measures incorporated all of the mechanisms which were employed within the study, whilst removed significantly correlated variables of vertical jump and linear sprint performance.

Table 6.13. Spearman’s ρ correlations of growth development variables.

Variable comparison 1	Variable comparison 2	Spearman’s ρ	[1] *p*-value
Standing stature (cm)	Body mass (kg)	-0.036	0.8706
Seated stature (cm)	Body mass (kg)	0.3209	0.1355
Seated stature (cm)	Standing stature (cm)	0.4382	0.0365*

[1] All significant *p*-values are labelled accordingly: ≤ 0.05*.

Table 6.14. Significant Spearman’s ρ correlations of physical fitness development variables.

Variable comparison 1	Variable comparison 2	Spearman’s ρ	[1] *p*-value
Df lunge right (cm)	Sit and reach (cm)	0.4938	0.0166
CMJ: ecc mf (N)	CMJ: conc mean force (N)	0.5596	0.0127
CMJ: pf (N)	CMJ: conc mean force (N)	0.5596	0.0127
CMJ: jump height (cm)	NF imbalance (%)	0.6294	0.0090
NF imbalance (%)	Mean NF (N)	0.4739	0.0469
Add strength (45^0) (mmHg)	Sit and reach (cm)	0.6138	0.0052
Add strength (45^0) (mmHg)	CMJ: conc mf (N)	-0.5451	0.0290
20 m linear sprint (s)	Df lunge left (cm)	-0.6172	0.0246
20 m linear sprint (s)	NF imbalance (%)	0.6606	0.0376
20 m linear sprint (s)	5 m linear sprint (s)	0.7366	0.0041
30 m linear sprint (s)	20 m linear sprint (s)	0.8886	< 0.0001
505-agility Left (s)	Df lunge right (cm)	0.5926	0.0423
505-agility Left (s)	CMJ: conc mf (N)	-0.6319	0.05
505-agility Right (s)	CMJ: jump height (cm)	-0.8632	0.0013
505-agility Right (s)	505-agility Left (s)	0.6208	0.0312

Df, dorsiflexion; Add, adductor; degrees (^{0}) of flexion for adductor strength refers to flexion of the hip; CMJ, counter movement jump; NF, Nordic force; conc, concentric; ecc, eccentric; mf, mean force; pf, peak force.

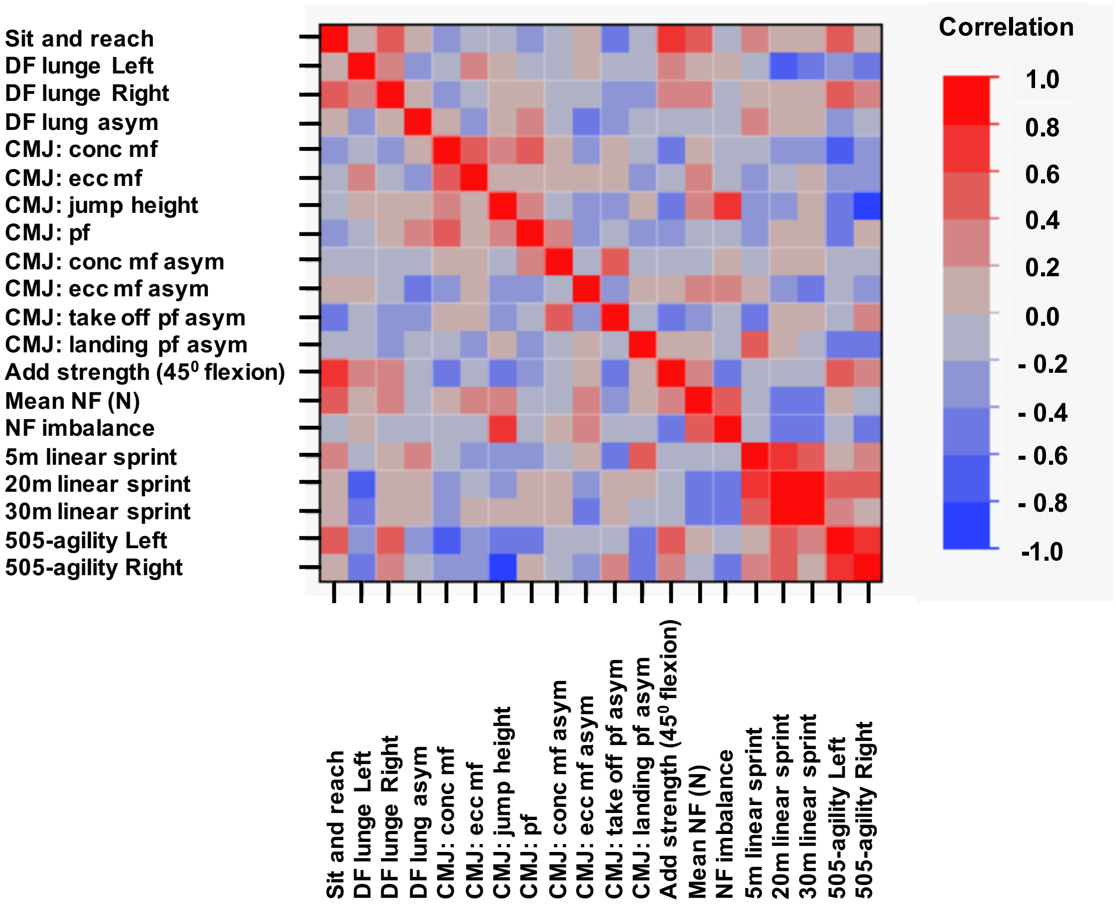

Figure 6.5. Colour map of Spearman's ρ correlations of physical fitness development variables. Df, dorsiflexion; Add, adductor; degrees (^{0}) of flexion for adductor strength refers to flexion of the hip; CMJ, counter movement jump; NF, Nordic force; conc, concentric; ecc, eccentric; mf, mean force; pf, peak force.

6.5.5.2 Correlations of psychological variables

Multiple significant correlations were observed between each of the measures of personality, coping, stress and recovery (Table 6.14). Multiple notable correlations were observed between variables, for example, correlations were observed between Recovery and Stress, both Sport Specific and General (p = 0.0280 to p = 0.0466). Both Sport Specific and General Stress had numerous correlations with coping variables (p = 0.0015 to p = 0.0362).

Table 6.15. Significant Spearman's ρ correlations of psychological variables.

Variable comparison 1	Variable comparison 2	Spearman's ρ	p-value
FFFS	Positive Reframing	0.4245	0.0387
BIS	Acceptance	-0.4570	0.0248
BAS	Global Stress	0.4686	0.0209
Active Coping	Positive Reframing	0.4571	0.0247
Active Coping	Planning	0.6214	0.0012
Substance Use	Behavioural Disengagement	0.5039	0.0121
Substance Use	Venting	0.5068	0.0115
Use of Emotional Support	Use of Instrumental Support	0.4615	0.0232
Planning	Positive Reframing	0.5487	0.0055
Substance Use	Humour	0.5502	0.0053
Acceptance	Positive Reframing	0.4475	0.0283
Acceptance	Humour	0.4085	0.0475
Self-Blame	Venting	0.4600	0.0237
Global Stress	Acceptance	0.5060	0.0116
Global Stress	General Recovery	0.4392	0.0280
Global Stress	Sport Stress	0.4300	0.0319
Global Stress	General Stress	0.6985	> 0.0001
General Stress	Venting	0.4965	0.0136
General Stress	Self-Blame	0.4446	0.0295
General Stress	Sport Recovery	0.4108	0.0414
General Stress	General Recovery	0.5854	0.0021
Sport Stress	Venting	0.5507	0.0053
Sport Stress	Planning	0.4294	0.0362
General Recovery	Behavioural Disengagement	0.4499	0.0274
General Recovery	Sport Recovery	0.4015	0.466

FFFS, Fight-flight-freeze system; BIS, Behavioural inhibition system.

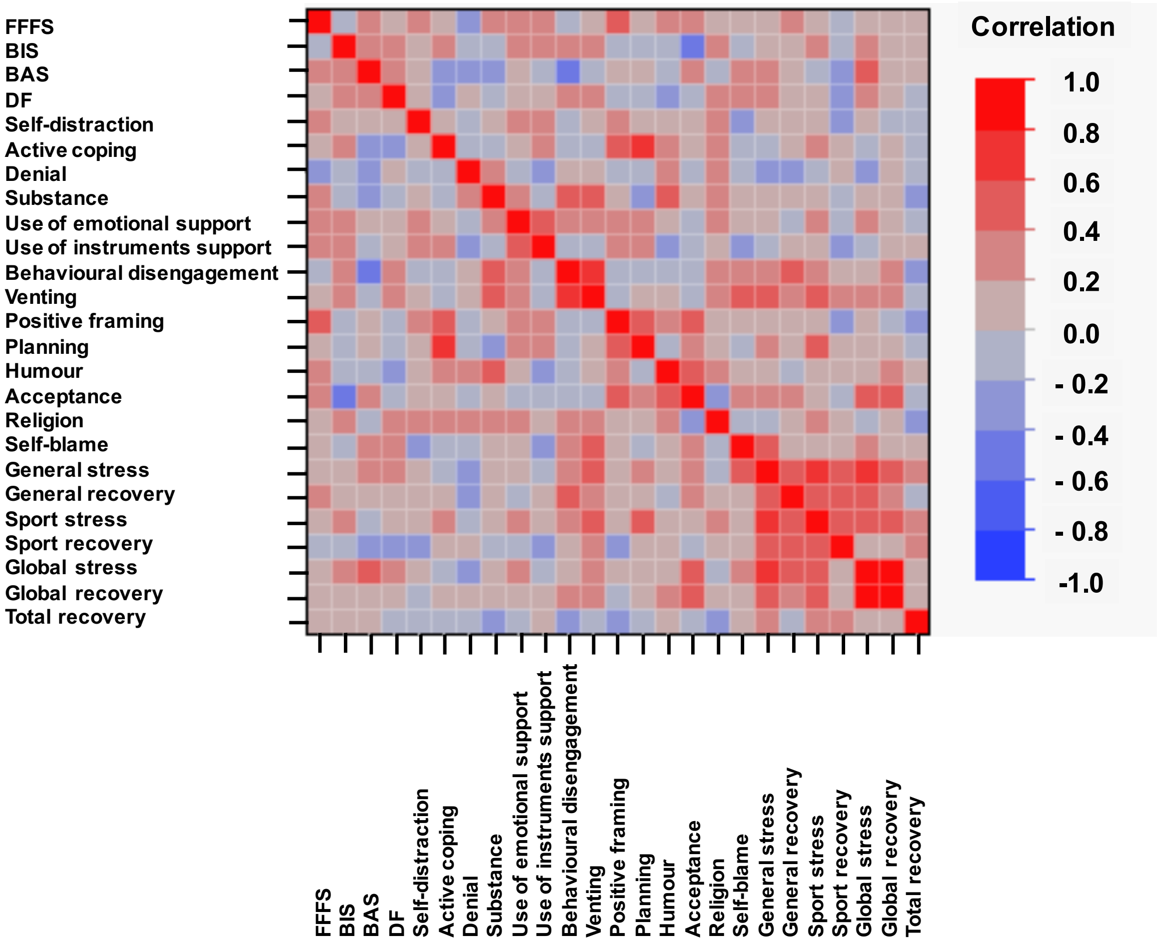

Figure 6.6. Colour map of Spearman's ρ correlations of psychological variables.

FFFS, Fight-flight-freeze system; BIS, Behavioural inhibition system; BAS, Behavioural Approach System; DF, Defensive fight.

6.5.5.3 Correlations of growth, physical fitness and psychological components

The correlational analysis that examined components of growth, physical fitness and psychological variables allowed for novel relationships to be observed within EPPP footballers. Details of how physical development and psychological variables were separated for final correlations and their anticipated relationship to each other are displayed within Figure 6.6. Growth development was anticipated to effect physical fitness development. As well as psychological changes of personality and coping, and fluctuations of stress and recovery both affecting and being affected by growth and physical fitness development.

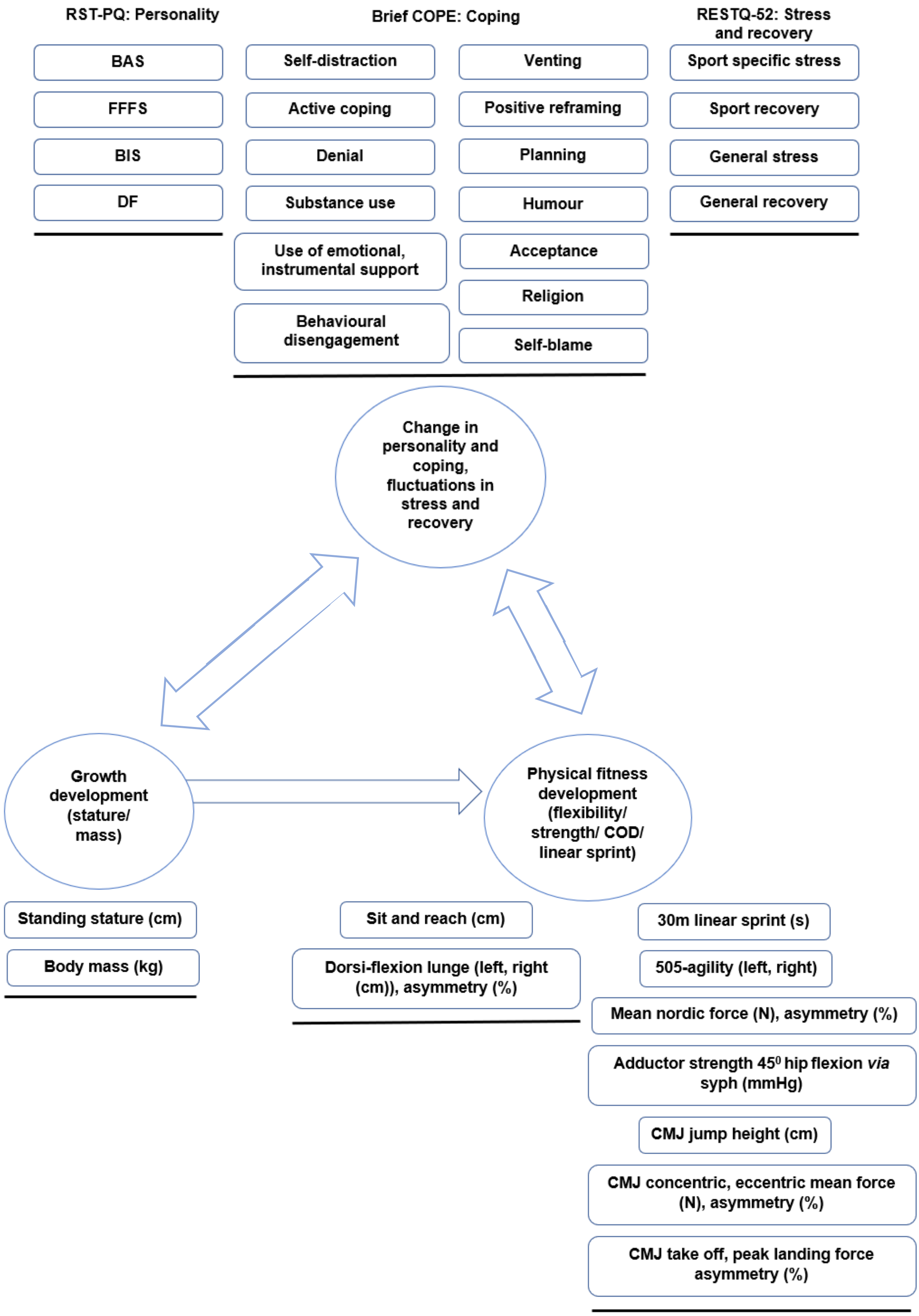
RST-PQ: Personality
BAS
FFFS
BIS
DF
Brief COPE: Coping
Self-distraction
Active coping
Denial
Substance use
Use of emotional, instrumental support
Behavioural disengagement
Venting
Positive reframing
Planning
Humour
Acceptance
Religion
Self-blame
RESTQ-52: Stress and recovery
Sport specific stress
Sport recovery
General stress
General recovery
Change in personality and coping, fluctuations in stress and recovery
Growth development (stature/ mass)
Physical fitness development (flexibility/ strength/ COD/ linear sprint)
Standing stature (cm)
Body mass (kg)
Sit and reach (cm)
Dorsi-flexion lunge (left, right (cm)), asymmetry (%)
30m linear sprint (s)
505-agility (left, right)
Mean nordic force (N), asymmetry (%)
Adductor strength 45⁰ hip flexion via syph (mmHg)
CMJ jump height (cm)
CMJ concentric, eccentric mean force (N), asymmetry (%)
CMJ take off, peak landing force asymmetry (%)

Figure 6.7. Conceptual framework for final correlations. The change and fluctuations in scores throughout the season are grouped within the circles, these variables were selected following the data reduction process described earlier. Arrows indicate the anticipated relationships between grouped variables of growth, physical fitness and psychological variables. Note: RST-PQ, Reinforcement Sensitivity Theory of Personality Questionnaire; RESTQ-52, Recovery-Stress Questionnaire for Athletes; BAS, Behavioural Approach System factors; BIS, Behavioural Inhibition System; FFFS, Fight-Flight-Freeze System; DF, Defensive Fight; sphy, sphygmomanometer; CMJ, countermovement jump; COD, change of direction.

From the final correlations, relationships between growth development and physical fitness development were shown, with increases in body mass being correlated with improved CMJ eccentric mean force and mean NF ($p < 0.0001$). Correlations were observed between the growth and psychological variables. Notably, when body mass increased so did Defensive Fight ($p = 0.0332$) and when standing stature increased, so did Denial ($p = 0.0038$). A number of correlations were demonstrated between physical fitness development variables and psychological coping variables. For example, when 30 m linear sprint times improved Self-Blame decreased ($p = 0.0061$). CMJ eccentric mean force showed correlations to personality variables of BAS ($p = 0.0487$) and DF ($p = 0.0043$); in each case all variables increased. Of note, numerous CMJ variables particularly peak landing asymmetry, had correlations with personality variables (significant correlations are given in Table 6.15).

Table 6.16. Significant Spearman's ρ correlations of physical and psychological variables.

Variable comparison 1	Variable comparison 2	Spearman's ρ	^{1} p-value
Body mass (kg)	DF	0.4359	0.0332
Body mass (kg)	Mean NF (N)	0.7998	< 0.0001
Body mass (kg)	CMJ ecc mf (N)	0.7998	< 0.0001
Standing stature (cm)	Denial	0.5784	0.0038
Df lunge left (cm)	Substance	-0.4238	0.0390
Sit and reach (cm)	Use of Emotional Support	0.4263	0.0425
Sit and reach (cm)	Use of Instrumental Support	0.43	0.0406
CMJ jump height (cm)	Total Recovery	-0.5175	0.0232
CMJ: conc mf (N)	DF	0.5471	0.0153
CMJ ecc mf (N)	BAS	0.5471	0.0153
CMJ ecc mf (N)	DF	0.6246	0.0043
Mean NF (N)	Denial	0.4949	0.0368
30 m sprint (s)	Self-Blame	-0.7139	0.0061

BAS, Behavioural approach system factors; DF, Defensive fight Df, dorsiflexion; CMJ, counter movement jump; NF, Nordic force; conc, concentric; ecc, eccentric; mf, mean force.

6.6 Discussion

Non-contact injury is a significant cause of lost participation in training and matches, amongst EPPP academy footballers, particularly because it leads to long absences from training and matches (Jones *et al*., 2019; Read *et al*., 2018a and b). Developing physical fitness training components such as strength and flexibility are important within EPPP academies to reduce injury risk and return players from injury (Read *et al*., 2018a). The pre-season period is a valuable time to prepare footballers for the competitive season (Bowen *et al*., 2017; Ekstrand *et al*., 2019). Within the present study, neither low availability across the pre-season nor differences in physical and psychological scores indicated future low availability across the competitive season.

Despite significant differences in training and matches missed between availability groups, no evidence of physical development differences was found across the pre-season. However, across the competitive season, players with low availability were able to increase their CMJ eccentric mean force to a greater extent than the players with high availability. Furthermore, CMJ take-off peak force asymmetry was also shown to increase within players with low availability. These particular findings would suggest that those who are available for more training and matches are exposed to greater volumes of pitch-based activity across a season. Therefore, these players may accumulate greater fatigue, which impairs neuromuscular capabilities and blunts strength development from impairment of localised muscle engagement as a result of high volumes of aerobic-based activity (e.g., Sporer and Wenger, 2003; Noon *et al.*, 2015). This could also suggest that when players are unable to participate in pitch-based activity, they should have an opportunity to have greater focus on their strength development and improve specific physical fitness performance aspects if they are physically capable. This would involve a variation in priority of exercise stimulus (high volume of aerobic pitch-based activity to strength-based training) with for example, specific resistance-based interventions being employed over 'weekly' meso-cycle periods (Kohavi *et al.*, 2020).

The use of other models may help to evaluate this further. For example, Banister's fitness fatigue model demonstrates that training stresses can alter physiological responses. Notably, training has positive (fitness) and negative (fatigue) after-effects that impact on performance and are proportional to the intensity and length of the athlete's training regime (Banister, Macdougall and Wenger, 1991). Levels of fitness and fatigue after-effects in a player will not remain fixed. Hence, a player who continues to train while fatigued will likely exacerbate their levels of fatigue leading to further maladaptation (Banister, Macdougall and Wenger, 1991). Any stimulus prescribed to athletes would be considered influential with respect to the magnitude and duration of training after-effects (Banister, Macdougall and Wenger, 1991). It has been suggested that even a single training session, particularly high volume, can increase the length of time associated with the fatigue effect (Busso *et al*., 2002). Importantly, the intensity and frequency of training sessions within the training year may be critical in relation to the levels of fatigue and time to recover. It is suggested that training early in the season is manageable before fatigue levels have accumulated; but recovery is impaired by high frequency training throughout the season (Busso *et al*., 2002; Meeusen *et al.,* 2013), Conversely, acute fatigue caused by high volume training is necessary to maintain or improve physiological characteristics (Meeusen *et al.,* 2013). It could be questioned whether high training volumes do indeed best facilitate appropriate physiological adaptions within EPPP academy footballers (e.g., Noon *et al*., 2015; Read *et al*., 2018a and b). Therefore, careful consideration should be given as to how to manage training volumes for elite academy footballers (e.g., Noon *et al*., 2015; Read *et al*., 2018a and b). As discussed in Study 2 examining dose-response relationships through a combination of external and internal load measures, could offer a solution to help identify the influence of fatigue with varying training volumes (Akubat, 2012). Further examination into the effect that various levels of pitch-based training volume have on strength development within EPPP footballers would be insightful; however, both external and internal measures should be considered to better understand the effects of training stimulus. Recently, it was demonstrated that elite senior footballers (age 19 ± 2 years) who suffer from severe injuries (> 28 days' time-loss), regardless of a return to pitch-based training and competition and without reductions in vertical-jump performance, still exhibit significant strength imbalances in both concentric and the eccentric phase variables of a CMJ with exception of eccentric deceleration impulse (Hart *et al*., 2019). Similarly, the present study's findings indicate that when rehabilitating, injured players are able to maintain, regenerate or improve their eccentric jump performance, though they will use ‘compensatory strategies’ to apply force (Hart *et al*., 2019), resulting in larger chronic asymmetrical differences between limbs, in-turn resulting in even greater risk to re-injury (Bourne *et al*., 2018; Read *et al*., 2018a). Though comparisons between studies can be problematic due to variations in the methodologies, such as calculations of asymmetries between limbs (Hart *et al*., 2019) and the differences in variables, these findings suggest that monitoring unilateral discrepancies between limbs is necessary for vertical jump performance in players returning from injury. These ‘at risk players’ can be prescribed appropriate strength-based stimuluses’ resulting in appropriate muscular adaptations, reducing the asymmetry differences between limbs, which can mediate further risk to injury (Bourne *et al*., 2018; Hart *et al*., 2019). If these monitoring procedures are conducted during players’ rehabilitation processes as early as it is safe and appropriate for the player to do so, then asymmetry differences can be highlighted, and interventions applied prior to players returning to pitch-based training. As injured players will have had extended periods of time out from training and matches, upon returning they could be at a higher risk of injury occurrence and therefore face further time out (Bourne *et al*., 2018, Read *et al*., 2018a).

A reduction in active coping and positive reframing was noted at the end of the season compared to the start of the season in players with moderate availability. This indicates a change in adaptation of their coping resources, possibly from changing their coping options through secondary appraisal as shown by others (Carver, 1997; Lazarus, 1999). Coping resources are highlighted as a contributor to stress-responses potentially contributing to injury risk (Williams and Andersen, 1998), with ineffective coping resources associated with increased injury risk in elite youth footballers (Johnson and Ivarsson, 2011). Within elite senior footballers, Brief COPE variables of Self-Blame and

Acceptance contributed to 14.6% of injury occurrences across three months (Ivarsson and Johnson, 2010). There is always the risk that changes in coping resources could result in players having less capability to cope with daily stressors (Pillow, Zautra and Sandler, 1996), impairing their well-being and possibly recovery processes, increasing negative life-event stress and increased injury risk (Johnson and Ivarsson, 2011). Adolescents within the age range of 14 to 18 years are at a delicate psychosocial developmental phase, in which they have less advanced coping skills compared to older individuals (Wylleman, Alfermann and Lavallee, 2004). Therefore, one could consider observing how these players change their coping skills when they go through intense stressful periods; for example, injury occurrence within a critical period prior to attaining a professional contract. For their well-being, it is necessary to determine if they are developing the appropriate coping skills to be able to handle the stressful psychological demands associated with elite senior football (Ivarsson and Johnson, 2010; Swainston, Wilson and Jones, 2020). In the present study, players with low availability had greater fluctuations in Total Stress and Recovery compared to those with high availability, although no significant differences were observed for the mean scores, or any of the General and Sport Specific Stress and Recovery subscales. Fluctuations in Total Stress and Recovery may have been influenced by the reaction of low availability players to a stressful event such as a severe injury. Overall, this might affect their stress levels and recovery acutely, but did not have a chronic influence over the remainder of the competitive season. This lack of chronic influence could be due to these players having appropriate coping resources (which did not significantly change over the competitive season), to enable them to adapt to the stressful event. The notion of hormesis could be considered for when players adapt to a stressful event. Hormesis underscores our understanding of the conditioning benefits of exercise and how low to moderate levels of physiological and psychological stress can stimulate adaptive responses enabling, or conditioning, the individual to cope better, or adapt to, more stress over the longer-term (Peake *et al*., 2015). The effect of acute stress levels on injury risk in elite youth and senior players is known (Brink *et al*., 2004; Laux *et al*., 2015). Monitoring recovery-stress balance and coping resources in players could be used for injury prediction and to protect players' wellbeing during rehabilitation processes (Brink *et al*., 2004).

Independent of injury, CMJ concentric mean force and jump height development demonstrated a potential relationship to improved change of direction times across the season (ranging from p = 0.0013 to p = 0.05). Previously shown, in elite academy footballers, CMJ focused plyometric training can increase vertical jump and change of direction performance (Thomas, French and Hayes, 2009). It is anticipated that strength and power-based interventions enable neuromuscular adaptations, therefore increasing leg muscle power (Mayhew *et al*., 1989) and reactive strength (Young, James and Montgomery, 2002). Players involved within the present study completed weekly gym-based sessions if they were able, which included a focus on improving leg power and RFD development such as through vertical force. As the extent of improvements are deemed to be relative to the specificity of the training stimulus, these players could have had an adequate stimulus to improve concentric vertical force which in turn could have had an influence on improved change of direction performance. However, increased maximal force may have resulted in asymmetrical NF changes which negatively impaired sprint development. The functions of the hamstring muscle and HSI are associated with sprinting mechanisms (e.g., Chumanov, Heiderscheit and Thelen, 2011; Kalkhoven *et al*., 2020). Neuromuscular training programs consisting of eccentric, plyometric and sprinting based interventions can stimulate hamstring strength and maintain sprint performance in adult footballers (Mendiguchia *et al*., 2015). All of the participants within the present study were exposed to 'weekly' training sessions which incorporated all of these interventions. Whilst players can improve in aspects of physical strength, hamstring imbalances need to be accounted for, corrected or minimised, as an individual NF imbalance score ≥ 15% puts players at an elevated risk of future HSI occurrence (Bourne *et al*., 2018; Opar *et al*., 2013). As highlighted previously, minimising asymmetry differences can be achieved through unilateral muscular adaptational processes by applying interventions such as unilateral strength-based stimuli (Bourne *et al*., 2018).

As described within Studies 1 and 2 changes in growth could influence the development of physical fitness (Stratton and Oliver, 2013). Findings in Study 1 and 2 were confirmed within the present study, as when body mass increased so did NF and CMJ eccentric mean force (< 0.0001). A relationship was also shown between body mass gain and DF, indicating that increases in connective tissue could be influenced by increased aggression and dominant characteristics or *vice versa*. Numerous relationships were shown between physical development and changes in coping resources. Increases in denial indicated possible increases in stature and NF, whilst decreases in substance use and increases in emotional and instrumental support possibly facilitated increases in posterior flexibility. Total Recovery and personality factors from BAS and DF were shown to possibly impact on vertical jump performance, where again greater increases aggression could result in physiological adaptations conducive to increased CMJ eccentric mean force. Collectively, these relationships indicate that physical development could be influenced by psychological development and *vice versa*. It is acknowledged that correlation does not indicate causation (Ryan *et al*., 2018). However, it would be beneficial to explore further whether psychological based interventions can help adapt coping resources to sport specific stressors to facilitate physical fitness development

(Nicholls *et al.*, 2020). Building on this research, academies could examine whether psychological interventions could facilitate player's physical fitness development.

6.6.1 Limitations

This study participant cohort only involves 25 participants. Pitch-based exposure data *via* time-motion analysis could not be included within the study, neither could autonomic nervous system variations which could have been paired alongside administrations of the RESTQ-52. There were a higher number of data points across the season for physical measures than the RST-PQ and Brief COPE psychological measures. This was primarily due to the nature of the testing environment as the psychological measures could only be employed at specific set periods so as to avoid interference with the player's development programme at the start of the pre-season. As the RESTQ-52 was collected cumulatively each month across the competitive season instead of the original guidelines of completing the measure every 3 days, memory bias could have been influenced (Laux *et al.*, 2015).

The findings presented here should be viewed with caution due to the study's exploratory nature and small sample size. However, the data will help to inform the design and implementation of further investigations using much larger cohorts across multiple participating academies. Hence, Study 3 should be considered an observational starting point rather than as conclusive. External and Internal load measures were not included as they could not be completed repeatedly and reliably due to testing complications across the entire testing period.

6.6.2 Conclusions

To conclude, non-contact injuries can have considerable effects on EPPP footballers training and match availability through a season. Although players can be constrained with pitch-based absence, they can improve eccentric parameters of their vertical jump performance to a greater extent compared to those participating weekly in pitch-based activity. However, despite this improvement, asymmetry strength differences for vertical jump performance are increased, constraining these players in a vulnerable position of re-injury risk. Similarly, independent of injury, whilst an appropriate strength-based stimulus could help facilitate change of direction speed and maximal force development, eccentric knee flexor strength imbalance can also be increased, thus impairing sprint development. The implementation of appropriate strength-based asymmetry interventions (stimuli) and monitoring procedures could help to combat maladaptive processes and compensatory strategies in and out of periods of rehabilitation. Higher stress and recovery fluctuations and reduced adaptive coping resources are associated with low and moderate availability, respectively. Furthermore, changes across a season in personality, coping resources, stress and recovery could affect physical development and *vice versa*. Future insight as to whether psychological-based interventions could help facilitate a player's physical fitness development would be interesting. In combination, these findings highlight the possible requirement for academies to monitor players' physical and psychological development and fluctuations, regardless of player's capacities to perform. A combination of psychological support and procedures to help players develop and maintain their coping resources, when they experience lengthy periods in and out of training and competing, could also potentially help facilitate physical development.

Chapter 7: Discussion

7.0 General discussion

The aim of this discussion is to review the structure of the project and its' findings to help facilitate future research and monitoring procedures of elite youth footballers within academy football environments. This chapter is comprised of the following sections: a brief overview of what the thesis entailed (7.1); the project's main findings and key theoretical issues, and their relationship to previous reported findings (7.2); an analysis of measurements within the thesis (7.3); practical implications and how these can be applied within academy football environments (7.4); where future research could be directed, if similar studies were conducted (7.5); strengths and limitations identified within the project (7.6), and a conclusion (7.7).

7.1 Overview of the thesis

Being able to support the development of youth footballers to an elite senior standard is a substantial task for football academies, which requires a significant investment of money, effort and time. Elite academy footballers face multiple challenges during this progression, including the ever-increasing physical fitness and psychological demands and pressures, the high playing standards and the competitive nature of elite senior first team football (Haugaasen and Jordet, 2012; Swainston *et al.*, 2020; Wilson and Jones, 2020). Ideally, players need to be available to train and compete as much as possible to be exposed to these psychological and physical demands, and to adapt appropriately to them. Alongside contact injury and illness, non-contact injury occurrence is a significant factor that influences whether a footballer is able to train and compete (e.g., Brink *et al.,* 2010; Read *et al.,* 2018b; Tears, Chesterton and Wijnbergen, 2018).

The findings presented in this thesis give an indication of the impact that non-contact injury can have on a player's training and match availability, with potentially detrimental effects on their technical and tactical development and future career progression.

The overarching aims of this thesis were to identify 'injury risks' and to understand the consequences of non-contact injury in a cohort of elite academy footballers. These analyses encompassed an extensive range of physical measures within three separate longitudinal observations and in combination with the unique use of psychological measures to adopt an interdisciplinary approach in Study 3. The project utilised an adapted version of a dynamic, recursive model of aetiology in sports injury (Meeuwise *et al.*, 2007), with the incorporation of psychological factors from the stress and injury model of Williams and Andersen (Williams and Andersen, 1998) (Figure 7.1). Both models guided selection of the assessments incorporated within the project, to best evaluate the intrinsic and extrinsic injury risk factors to which the participants would be exposed during a playing season. Physical measures of growth, physical fitness and pitch-based exposure (Studies 1, 2, and 3) and psychological measures of personality, coping, stress, and recovery (Study 3) were incorporated within the thesis. These measures were compared against the impact of non-contact injury occurrences; HSI in isolation (Study 1) and profiles of reduced availability for training and matches, affected by any non-contact injury (Studies 2 and 3).

The participant cohort spanned the 'professional phase' age groups (U16 to U23) within an individual EPPP category 1 academy. Study 1 involved players aged from 14.1 to 23.0 years; participants in Studies 2 and 3 were aged between 15.9 and 18.5 years within the U18 age group. Studies 2 and 3 involved the U18 age group only, because prior studies had highlighted increased injury rates and higher severity of injuries in U18s (e.g., Read *et al.,* 2018b; Renshaw and Goodwin, 2016). Furthermore, the most critical step to progressing to elite senior football is associated with this age range (Swainston *et al.*, 2020). Also, testing complications meant the U18 age group were the only professional phase age group that could be monitored utilising the project's testing battery and availability data across longitudinal periods (seasons). These parameters were considered more essential to prioritise and evaluate than increasing participant numbers.

7.2 Theoretical and methodological implications

The specific aims of the thesis highlighted in Chapter 1 guided the design and implementation of the three studies (Chapters 4, 5 and 6). The findings and whether they met the stated aims are discussed below.

7.2.1 Influence of non-contact injury on training and matches

The influence of HSI occurrence within a season was observed within Study 1. Players who sustained a HSI, were unable to participate in training and matches over a period of 13 ± 9 days; (min, 2; max, 33) and missed 2 ± 2; (min 0; max 5) matches. However, when levels of match exposure time were analysed against HSI occurrence no significant differences were found compared to players who did not sustain HSI, although a large amount of match exposure time was lost (409 ± 283 mins). The large amount of playing time lost gave an indication that the influence of a HSI may extend beyond the period when the player is unavailable for selection. This results in players needing sufficient time to re-establish themselves within match-day squads. A specific aim for Study 1 was to assess HSI on match exposure over a season. Whilst match exposure time does give an initial viewpoint into a level of exposure and provides valuable insights into the specific time lost, it does not give a full insight because quantified running exposure metrics were not observed. Therefore, it could be considered that this aim has been examined in part, but to address this further, exposure monitoring tools such as time-motion analyses, if available, should be applied.

Studies 2 and 3 examined participant availability for training and matches affected by non-contact injury following categorisation of groups based on their match and training attendance profiles. Similar to previous literature (e.g., Jones *et al*., 2019; Read *et al*., 2018a and b; Tears, Chesterton, and Wijnbergen, 2018), it was established that some players within the U18 age group lost a large amount of training and match attendance because of non-contact injury. These non-contact injuries can vary in severity across cumulative seasons and within particular periods of the season such as the pre-season and competitive season (see Studies 2 and 3). Variations in levels of attendance indicated the advantages that some players have over others, to increase their playing experience and to develop their playing ability, for example, increasing tactical, conditioning and technical performance within pitch-based activity (Memmert, 2010). It is critical that youth players develop and improve technical and tactical performance to reach a level which is acceptable and compatible with an elite standard of football (Jones *et al*., 2019; Ward *et al*., 2007).

Study 2 aimed to assess the impact of reduced availability due to non-contact injury on players' training and match exposure. Training and match exposure levels recorded by time-motion analyses were compared against levels of availability influenced by non-contact injury. Both training and match exposure differed only between players with high and low availability. Players with high availability had a higher total PlayerLoad and covered a greater total distance in training and matches, where they also accumulated a higher volume of HSR, explosive distance and sprints. No other differences were observed between the availability groups for any of the other training, or match time-motion variables. As part of the rehabilitation process, injured players, if capable of doing so, can be gradually exposed to running based movements to help them develop the load tolerance necessary to manage team training sessions (Mendiguchia *et al*., 2014). As part of Study 2 participants were equipped with GPS devices within rehabilitation sessions to record their running and training exposure. These findings could demonstrate that when injured, and removed from team pitch-based training, players can still cover some of the specific movement velocities required within team training sessions across a season during rehabilitation. However, they will not be exposed to the same amounts of PlayerLoad or total distance. Even though a player can attain some movement exposure when rehabilitating, it does not alter the fact that they lose a large amount of coaching and playing experience and the vital pitch-based exposure essential for competition. Nonetheless, it is a positive that these players can maintain some volume of movement velocities from training-based scenarios only. This ensures that their transition back to full-participation is as efficient as possible and that they are able to tolerate the TLs required of them whilst not heightening the risk of re-injury (Bowen *et al*., 2017; Jeong *et al*., 2011). These findings illustrate the value of monitoring individual players' pitch-based rehabilitation. The cumulative time-motion analyses (Study 2) provide metric profiles of U18 players following their exposure to pitch-based activity across a season. Movement profiles such as these can be compared against other stages of a player's development including the U23 age group and elite senior football. However, it should be acknowledged that the profiles generated by the current project reflect the influence of non-contact injury rather than individualised positional demands as described previously (Hewitt, 2014). GPS-based research is still in its infancy and so data collection and curation need to evolve to account for the multifaceted considerations and complexities needed for time-motion analysis; this includes positional based variations (Bowen *et al*., 2017; Hewitt *et al*., 2014; Malone *et al*., 2017). Moreover, standardised operating procedures have yet to be formulated for time-motion analysis, which means that published research from academies are likely to differ when GPS is utilised. It has been stated that TL measures should not be applied in isolation to prevent injury due to the minimal research between relationships of injury and load exposure (Impellizzeri, *et al*., 2020). Therefore, while this project has completed the aim of assessing the impact of reduced availability due to non-contact injury on players' training and match exposure, future research should be focussed on the associations between exposure and injury risk. However, it has been acknowledged that conceptual and methodological considerations must be accounted for (Impellizzeri, *et al*., 2020). For example, Impellizzeri and collegues have highlighted methodological concerns surrounding the use of ratios such acute: chronic workload ratios and the subsequent risk of artifact ('noise), which raises concerns of data (mis)interpretation and the possibility of false relationships being identified between these ratios and injury occurrence (Impellizzeri, et al., 2020). As well as research focussing on team-based training, SOPs for the use of GPS should be developed, adhered to, and used more extensively during rehabilitation.

7.2.2 Influence of non-contact injury on physical and psychological development

The main aim within Study 1 was to assess the impact of HSI occurrence on physical development. Players who did not sustain a HSI increased NF and body mass over the season more than those who had sustained a HSI. Maladaptive de-training effects of eccentric strength are considered to be more rapid than concentric-based strength (Mujika and Padilla, 2000) and previous HSI and low eccentric hamstring strength are recognised as prominent HSI risk factors (Timmins *et al*., 2016a). Therefore, monitoring player's eccentric knee flexor strength whether they are HSI free, or rehabilitating, can help mitigate this risk. Studies 2 and 3 aimed to assess further the impact of non-contact injury on development. Observations across the season showed that players with lower availability for training and matches developed physical fitness no different to those who had significantly greater availability throughout the season. The lack of between group differences here may be explained by the fact that players when injured underwent rehabilitation that specifically focused on restoring physical fitness prior to returning to play (Jones *et al*., 2020). It has been suggested previously that when players are injured, they are able to concentrate greater efforts on specific exercise components such as strength (Lepley *et al*., 2019; Kohavi *et al*., 2020). Some evidence to support this was found when change in CMJ eccentric mean force was increased in injured players (in the low competitive season availability group) compared to those playing regularly (in the high availability group). As investigated in Study 3, these findings suggest a possible relationship between exposure of training and matches to inhibit adaptation of strength-based stimuli. If coaching staff consider that players need to prioritise increasing their physical strength over pitch-based activity, then specific interventions could be examined, such as carefully controlled and monitored pitch-based exposure for individuals or small groups of players. Such an approach could be used to target players of lower physical maturity, or those needing to reach specific physical strength levels required by their playing position (Gastin, Bennett, and Cook, 2013; Le Gall *et al*., 2010; Towlson *et al*., 2017), as long as it did not critically impact their playing development. However, when applying conditioning interventions to injured players the focus on asymmetrical imbalances between limbs needs to be considered (Bourne *et al*., 2018; Read *et al*., 2018a). This is because contralateral strength asymmetries between limbs were shown to increase to a greater extent. For example, players with low availability increased in CMJ take-off peak force asymmetry more than the players with high availability (Study 3). The use of compensatory strategies to maximally apply force whilst protecting damaged anatomical sites could result in increased injury risk (Read *et al*., 2018a; Opar *et al*., 2012a and b). Reduced performance through maladaptive degenerative processes is more likely to occur when a player has been removed from participation due to non-contact injury, resulting in inactivity (Rodríguez-Fernández *et al*., 2018). However, it was shown within the present project that some of these processes can be prevented or overcome when players have lengthy periods away from pitch-based team training-sessions and matches. Overall, analysis within the thesis on the influence of non-contact injury on physical development indicated that players could be at an increased further risk of injury re-occurrence when they return to training following rehabilitation despite improving in an area of physical strength.

From observations of psychological development (Study 3), the moderate availability group had reduced coping resources compared to the high availability group (Active Coping, Positive Reframing) over a season. As discussed, coping resources are a contributor to the stress-responses increasing injury risk (Williams and Andersen, 1998) with ineffective coping resources leading to increased injury risk within elite youth footballers (Johnson and Ivarsson, 2011). It is anticipated that players require suitable coping skills to be able to handle the psychological demands associated with elite senior football (Ivarsson and Johnson 2010; Swainston, 2020). Therefore, it is critical that individual players are monitored during (if possible), soon after their rehabilitation process and thereafter. It would also be helpful to include psychological measures unique to an EPPP environment to monitor coping resources of individual players, and if deemed necessary, the inclusion of psychological based interventions to help maintain or improve coping resources (Reese, Pittsinger and Yang, 2012). Otherwise, players may have less effective coping resources to deal with stressful events, be at further risk of injury and be unable to attain the appropriate level of physical development required of a higher playing standard of football.

7.2.3 Prediction of non-contact injury from physical and psychological measures

Due to the significance of identifying injury risk factors, aims were set across all three studies to identify potential risk factors which could either lead to HSI (Study 1) or reduced availability due to non-contact injury (Studies 1 and 2). Multiple physical measures and classification of age were employed across the three studies and psychological measures employed within Study 3. Of these measures, age predicted future HSI, with older players being more likely to sustain a HSI. Two of the physical measures, ranges of the sit and reach test and CMJ peak landing asymmetry, predicted future reduced availability (training and matches) affected by non-contact injury. Elite football environments are considered to be operating various testing batteries to screen players for intrinsic injury risks, although the methods and repeatability of these batteries will vary according to the preference of individual organisations (e.g., Read *et al.*, 2018a; Hughes *et al.*, 2020). In line with published literature, the physical fitness measures employed within the thesis addressed components of neuromuscular strength, flexibility, change of direction and linear sprint speed, and were taken at specific time-points in the season. Within Study 2 pre-season sit and reach scores gave an indication of future low availability. However, instead of these players exhibiting low flexibility scores (Jones *et al.*, 2005; Hatano *et al.*, 2019) they had significantly higher scores. Further examination of these scores and their range against previous literature indicated the likelihood of hypermobile characteristics (Kirkini *et al.*, 2019). This finding may differ from initial considerations made by practitioners when assessing injury risks, concerning impairment of hamstring flexibility. In accordance with the results in Study 2, a recent review of 734 youth footballers (U10 to U15) within Belgian academies across an entire season found that a lower sit and reach score indicated protection to injury risk while a higher score indicated a risk of injury (Rommers *et al*., 2020). Therefore, when academies screen players using measures of flexibility, consideration could be taken of both impaired flexibility (Jones *et al*., 2005; Hatano *et al*., 2019; Kirkini *et al*., 2019) and hypermobile characteristics to reduce future risk of non-contact injury (Le Gall *et al*., 2006). Higher CMJ peak landing force asymmetry scores at pre-season (Study 2) also suggested future low availability. Despite there being limited findings relating to landing asymmetry differences and injury rates within elite youth football cohorts, larger asymmetries resulting from reduced neuromuscular control would be an injury risk factor, particularly for lower limb ligament injuries (Read *et al*., 2016). Given that landing mechanics can deviate during the recovery processes post-match in elite youth footballers, practitioners could scrutinise landing-based mechanics as a measure of readiness to train and as a marker of injury risk at pre-season (Bromley *et al*., 2018).

Figure 7.1 displays the dynamic, recursive model of aetiology in sports injury adapted from Meeuwisse *et al*., (2007) and indicates how the findings surrounding physical and psychological development, exposure and intrinsic and extrinsic risks, affect the directional flow of the model. Frameworks such as the original sports injury model by Meeuwisse *et al*., (2007) are considered to lack sufficient detail of the causal relationship with injury (Kalkhoven, Watsford and Impellizzeri, 2020). In the writer's opinion, the sports injury model by Meeuwisse *et al*., (2007) provides a clear general process of injury and the adapted version shown here highlights the influence of intrinsic and extrinsic risk factors further. Other models could be considered by practitioners to help understand the cause of specific injuries (i.e., acute and overuse) in greater detail.

For example, a recent comprehensive framework for stress-related, strain-related, and overuse injury which focuses on components of load tolerance and load application, has been developed (Kalkhoven, Watsford and Impellizzeri, 2020). This supports the argument that injury research should provide greater explanations into injury causation and data collection protocols overviewing injury. These should include physiological factors alongside mechanical properties. Furthermore, to understand better how external factors cause injury a detailed analysis of the pathway that leads to injury needs to be conducted. This includes analysis of the mechanical and strength properties of tissues in response to the external forces applied and the resulting internal stresses and strains (Kalkhoven, Watsford, and Impellizzeri, 2020). Such methodological approaches could provide greater insight into specific injury type causation. However, to apply such an approach within an elite academy environment with a sufficiently large cohort, will depend on multiple factors including time, financial resources and specific SOPs. While it might be possible to secure funding for injury research, a more intractable problem would be to obtain agreements on the implementation and consistent use of SOPs across multiple academies. Likely this would necessitate considerable planning and mediation to ensure appropriate implementation, all of which could be problematic and challenging. These issues are not inconsequential and are discussed further below.

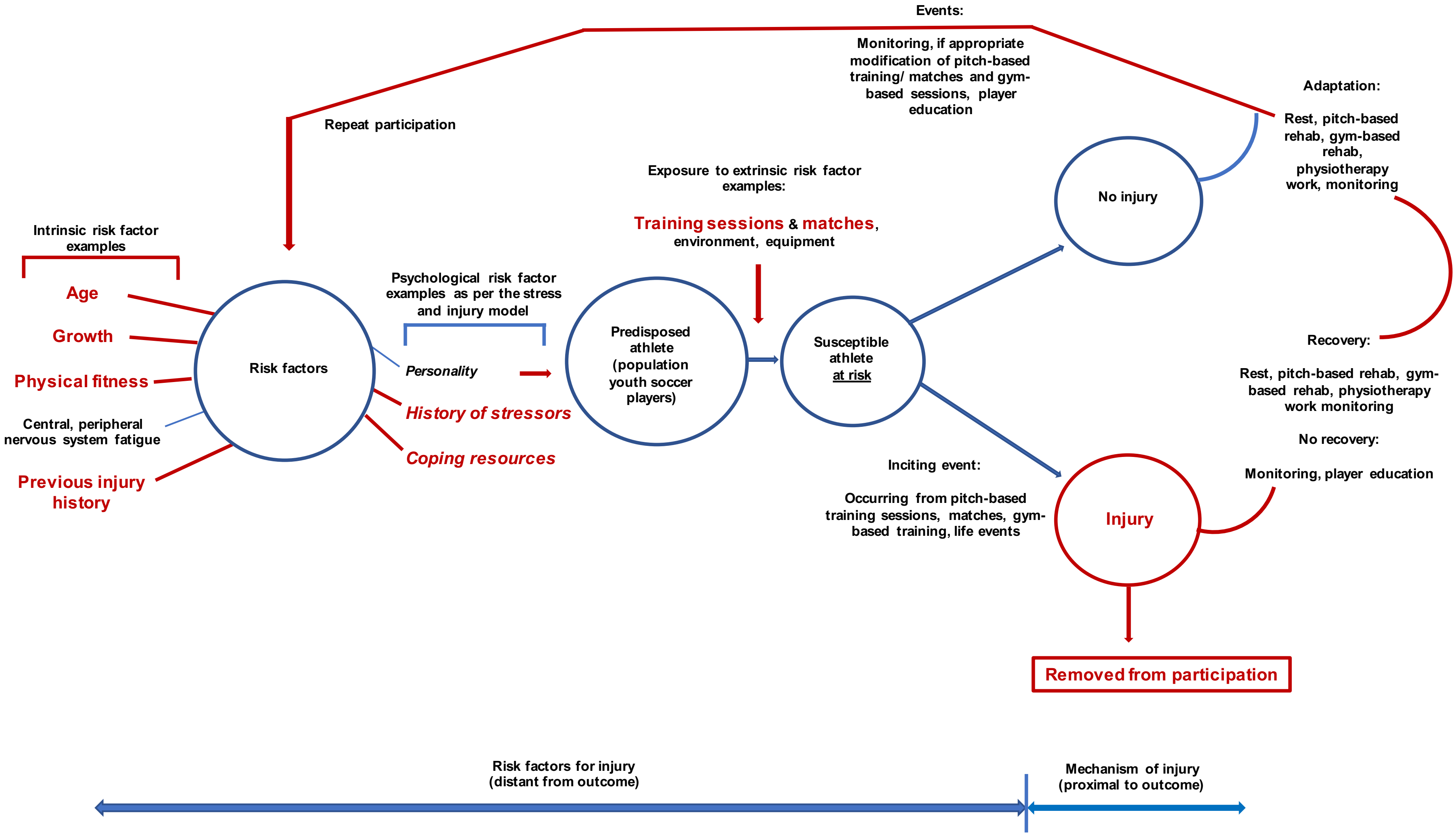
Events:
Monitoring, if appropriate modification of pitch-based training/ matches and gym-based sessions, player education
Repeat participation
Adaptation:
Rest, pitch-based rehab, gym-based rehab, physiotherapy work, monitoring
Exposure to extrinsic risk factor examples:
Training sessions & matches, environment, equipment
No injury
Intrinsic risk factor examples
Age
Growth
Physical fitness
Central, peripheral nervous system fatigue
Previous injury history
Risk factors
Psychological risk factor examples as per the stress and injury model
Personality
History of stressors
Coping resources
Predisposed athlete (population youth soccer players)
Susceptible athlete at risk
Recovery:
Rest, pitch-based rehab, gym-based rehab, physiotherapy work monitoring
No recovery:
Monitoring, player education
Inciting event:
Occurring from pitch-based training sessions, matches, gym-based training, life events
Injury
Removed from participation
Risk factors for injury (distant from outcome)
Mechanism of injury (proximal to outcome)

Figure 7.1. A dynamic, recursive model of aetiology in sports injury modified to show the impact of injury in EPPP footballers. This revised model has been adapted from that of Meeuwisse *et al*., (2007). Intrinsic and extrinsic physical risk factors and psychological components of personality, history of stressors and coping resources have been included which relate specifically to the academy youth football players who participated in this research project. In particular, findings from the thesis inform the impact of non-contact injury on the model's descriptive processes. Areas highlighted in red indicate sections of the model that have relevance to findings obtained within the present thesis. Assessments were made of the influence of non-contact injury and time-loss due to non-contact injury on player development (physical and psychological) across EPPP seasons. Examples of findings: Study 1, age as a risk of HSI, impaired growth and physical fitness following HSI; Study 2, physical fitness intrinsic risk factors resulting in reduced availability, reduced match exposure following reduced availability; Study 3, reduction in coping resources and increased physical fitness intrinsic risk following reduced availability.

7.2.4 Examination of the relationships between physical and psychological development measures

It is important to use the correct methods to facilitate the development of appropriate performance components for elite football (Hulse *et al*., 2013; Deprez *et al*., 2015). By identifying relationships between physical and psychological development variables, practitioners can predict better how and when player performance improvements may occur, which can then help guide prescribed training interventions. An aim across the three studies was to examine the relationships, independent of injury, between growth and physical fitness development, exposure and psychological development. It was anticipated that different components of growth, physical fitness, exposure of training and matches, and psychological aspects would be interrelated and, consequently, would affect each other (Figure 7.2). In addition, it was anticipated that growth could influence physical fitness and pitch-based exposure, and that physical fitness could be influenced by pitch-based exposure, and *vice versa*. Similarly, it was anticipated that changes in psychological aspects could be influenced by physical components and *vice versa* (Figure 7.2). Physical relationships were assessed *via* correlation-based analyses to various degrees within Studies 1, 2 and 3, whilst both physical and psychological relationships were examined within Study 3. Hence, all anticipated relationships between the components of growth, physical fitness, pitch-based exposure and psychological factors were analysed within the thesis with the exception of the relationships between training and match exposure against various psychological variables of personality, coping, stress and recovery (Figure 7.2). Whilst the aims stated were achieved, the observations of exposure with psychological development would provide a novel examination within elite youth footballers.

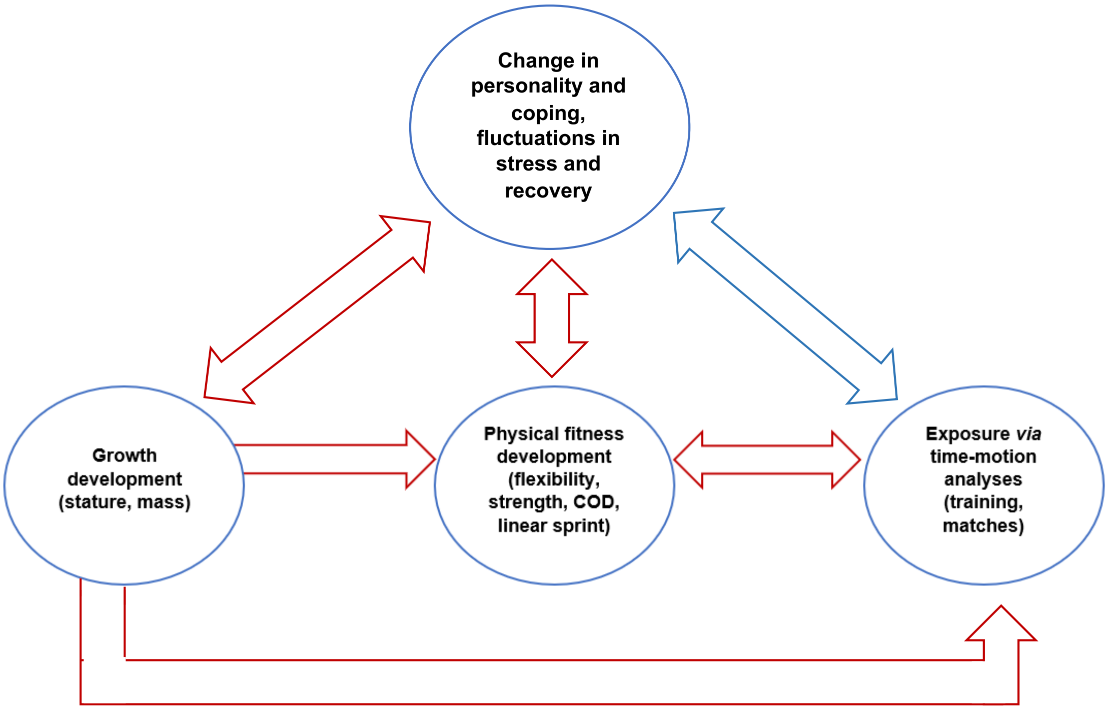

Figure 7.2. Conceptual framework for the anticipated impact from components of physical and psychological development and exposure. Circles represent the change scores for components of exposure and growth, physical fitness and psychological development variables across individual seasons. Arrows indicate the possible directional relationship between the grouped variables of exposure, growth, physical fitness and psychological variables incorporated within the thesis. Red arrows indicate correlations demonstrated between variables; the blue arrow is an anticipated potential directional relationship. COD, change of direction.

As anticipated, the correlation analyses indicated a number of relationships between each of the physical and psychological components (Figure 7.2). Performance advantages of young athletes with earlier maturity have been shown previously (Gastin, Bennett and Cook, 2013). Though similar to greater physical performance attributes, being heavier and taller are indications of higher playing standards (Le Gall *et al*., 2010; Study 2). As expected from previous research (Stratton and Oliver, 2013), multiple correlations were shown between growth and physical fitness. This indicated greater changes in growth (stature and body mass) reflecting improved neuromuscular physical fitness in areas such as linear sprint speed, eccentric knee flexor strength and vertical jump performance (Studies 1, 2 and 3). The only relationship shown between growth development and pitch-based exposure levels was increased seated stature with greater total PlayerLoad in matches. It has been acknowledged within current research that high training volumes stipulated by the EPPP may not be conducive to the development of neuromuscular fitness in EPPP footballers (Enright *et al*., 2015; Malone *et al*., 2015a). Within the present project, the identified relationships suggested that increased adductor and abductor hip strength could potentially help players tolerate greater pitch-based exposure. However, it was also found that increased CMJ eccentric asymmetry could hinder the accumulation of HSR within matches. These are important findings because, whilst training workloads can be reduced according to the perspectives of individual academies, to be able to expose players to an optimal amount of competition they need to be able to withstand the intense demands. These considerations could be applied to individual players dependent on their upcoming workload, for example, prescribing strength-based stimulus for the hip, to prepare players for a congested match schedule (Wollin *et al*., 2018). Furthermore, reducing asymmetrical dominance could enable players to cover greater volumes of HSR within matches. CMJ height remained the most consistently correlated measure between measures of growth (body mass and stature); exposure (training and match total PlayerLoad and HSR); and other improvements in physical fitness (linear sprint speed (20, 30 m), 505-agility, sit and reach, dorsiflexion lunge, abductor strength at 60^0 hip flexion and the variable of peak force obtained from the CMJ measure). The link between improved CMJ height, increased physical fitness attributes and greater pitch-based exposure, underlined how improved lower body strength translates to greater sprint and jump performance and supports previous findings (Comfort *et al.*, 2014). Therefore, CMJ jump height could be considered a variable which can anticipate other developed physical capacities within elite youth players. Notably, in Study 1, reduced NF imbalance signified possible improved linear sprint speed (20 m) whereas Study 3 showed that increased NF imbalance possibly improved linear sprint speed (20 m) and increased strength (CMJ jump height, mean NF). These findings signify the importance of being able to monitor and reduce asymmetry differences between limbs to reduce heightened injury risks, alongside developing maximal physical fitness performance outputs (Read *et al.*, 2018a; Bourne *et al.*, 2018). Whilst compensatory mechanisms may impair physical performance, some players can still improve despite using compensatory mechanisms. The use of a reduced data set that included growth, physical fitness and psychological variables (Study 3), gave the opportunity to observe the relationships between psychological factors and physical development within elite youth footballers, which to the author's knowledge has not yet been conducted. Of the relationships observed, personality variables such as DF were shown to be correlated with body mass gain and vertical jump performance. This indicated that when players adopt more aggressive characteristics it could influence areas of physical development or *vice versa*. Furthermore, coping resources were shown to be correlated to growth development (standing stature) and physical fitness development (i.e., sit and reach, 30 m linear sprint and mean NF). This indicates that if coping resources could be managed or enhanced then this could have a positive impact on the player's physical development, which could in itself be managed by appropriate psychological based interventions (Nicholls, 2020). These findings warrant further examination of the potential effect that psychological influences have on physical development, which could include exposure *via* time motion analyses of training and matches (which unfortunately could not be conducted within the present project). Overall, the data presented shows that changes in psychological components could influence physical development and improved performance outputs. Therefore, the influence of psychological based interventions on physical development could be examined in the future to help facilitate physical performance.

7.3 Conceptual and measurement issues

Interdisciplinary approaches permit a more holistic observation of various mechanisms in comparison to mono- and multi-disciplinary approaches. This allows for examination of the interactions of numerous separate factors (Freedson, 2009; Tobi and Kampen, 2018). Some elite academy football environments do incorporate interdisciplinary approaches to monitoring and interventions; but psychological influences are not examined to the same degree. The association between injury risk and psychological components has been reported within both elite youth and senior football (e.g., Brink *et al.*, 2010; Laux *et al.*, 2015). However, a combination of both physical and psychological influences on injury risk are not reported in any depth within the literature. If the adapted recursive model of aetiology in sports injury (Meeuwise *et al.*, 2007) outlined for this thesis (Figure 7.1) is used as a template, then academies can help to progress players through the directional flow of the model, when available to train and compete, injured, or returning to training (e.g., Lovell *et al.*, 2019b; Read 2018a).

However, what has been questioned is whether these approaches within academy football are appropriate with respect to current EPPP demands and elite sporting monitoring practices (Read *et al*., 2016; Read *et al*., 2018a). Also, if these monitoring approaches take into account all the multifaceted risk factors associated with injury and the components of physical and psychological development that could affect elite youth footballers who are at critical periods of their development (e.g., Brink *et al*., 2010; Read *et al.,* 2018b; Renshaw and Goodwin, 2016). For example, are the approaches capable of scrutinising sufficiently those monitoring periods where participants are most at risk of injury (Le Gall *et al*., 2006; Price *et al*., 2004; Read *et al*., 2018b; Woods *et al*., 2002). Careful consideration is required when designing an interdisciplinary framework, measurement and equipment selection, as well as data reliability and interpretation (Tobi and Kampen, 2018). In line with Tobi and Kampen's methodology for interdisciplinary research, the thesis examined (Chapter 3) whether specific measures could be employed reliably within testing batteries over cumulative seasons (Tobi and Kampen, 2018) within an EPPP academy. However, it was also necessary to establish if the selected measures could be repeated on a cumulative basis, over repeated seasons, within participant cohorts that were likely to change in their physical and psychological characteristics. These factors can result in differing levels of engagement to specific monitoring measures. Although a degree of planning can account for this, realistically, trial and error of how measures were employed and administered within specific batteries of tests was required. In addition, adaptation of practitioners and investigators when running testing protocols, such as in the present project, is necessary to allow measures to be collected reliably. Over a testing period there needs to be an ongoing review process to ensure that data relating to individual players and relevant feedback is being managed appropriately and effectively (execution processes). For example, if participants are not engaging with a specific measure, or are becoming injured, it requires rapid attention and, potentially, the adaptation of the testing processes to prevent further adverse events before the data are synthesised, curated, and reported. Within sporting environments for field-based testing there are many external factors which could impact on testing protocols which are difficult to control for, plus the time available for data to be collected, curated, and analysed is small and infrequent (McCall *et al*., 2016; Noon *et al*., 2015).

In elite football both youth and senior players are subjected to high levels of physical and psychological stress (Haugaasen and Jordet, 2012; Swainston *et al*., 2020). For an individual who has not been in this position previously, this can be hard to relate to. In particular, players within elite academy football are having to manage both their sporting and academic development, as well as any external stressors to which they are exposed. These stressors reflect every-day life, and the issues by which individuals within their age range are affected. For these players, it takes either considerable maturity to be able to adapt to their environment and to be able to cope with high levels of external stressors, or the ability to mature rapidly (Nicholls, 2020). This can create scenarios that have implications for the use of measures. For example, testing a player who has been told they will not have their contract renewed, which is a normal factor within any elite sporting environment at the end of each season. Therefore, as highlighted previously, being able to adapt prior to or during the execution of testing is critical and having an awareness and understanding of each individual player is beneficial.

What was noted during the data collection for the psychological measures (Study 3), was that more communication and time was required from the researcher compared to physical assessments. This included the need to introduce and explain the measures to the participants, to answer any questions, to request co-operation and to implement the measures around changes within weekly structure (differing between each individual participating). In contrast, the majority of participants were accustomed to the testing procedures used for the physical measures because of the performance structure of the academy. This difference might be unsurprising if players have not been tested psychologically in the past. It was important to determine whether psychological measures could be applied effectively in a fast-paced environment on a cumulative basis (McCall *et al*., 2016). Importantly, there has to be a level of trust and rapport between the participant and the researcher. Notably, if the practitioner could not commit the time to provide the level of detail required when gathering psychological measures, it is highly unlikely that the participant would be able to provide accurate and reliable information. When using any subjective measure, there was always the risk that participants may not answer some items within the questions as a true reflection of their current state. One concern was that players might answer items according to what they anticipate coaches and practitioners want to see, rather than as a true reflection of their current or previous psychological states. However, potential bias of the questionnaires was mediated as much as possible, by the questionnaires being completed individually with clear communication between the researcher and individual participants. This meant explaining the reasons and importance of the questionnaires, and the fact that the answers are kept confidential; the process was based on building trust between the player and the researcher.

Some of the equipment and software which was used within the project such as the NordBord, GroinBar, GPS devices and force platforms could be considered harder to acquire compared to measures requiring no cost. Therefore, some organisations may not seek to obtain the equipment and software, and maintain it, due to cost. No matter the type and quality of equipment there is always the risk of malfunction, error and damage, therefore prior to data collection consistent cumulative checks were required and where appropriate, calibration. Furthermore, a level of knowledge and experience is needed when applying measures with a specifically designed software, which requires training and time (Noon *et al.*, 2016). Without a full understanding of the equipment, testing protocols and how to interpret the data outputs, applying measures can be problematic and importantly can affect the reliability of the results. For some testing sessions, multiple measures had to be collected in unison to keep within the organisation's weekly schedule and not to overrun the time available for testing. For adductor and abductor strength measures, two external investigators were required who were comfortable with the protocols and aware that testing protocols for each measure were needed on four individual testing sessions within two playing seasons (two pre-season and two late season, 2017/18). In an ideal situation, the same testers would conduct the same tests over repeated testing sessions. Whilst each tester completed the testing protocols appropriately, the individuals did differ within one of the four testing sessions. This same issue can arise if practitioners leave the organisation, are limited in numbers and time, and are not available for appropriate days within the weekly schedule of the season to complete the monitoring screenings. It has been highlighted that academies have limited investments in internal research application (Enright *et al.*, 2015; Noon, 2016) and typically practitioners have high volumes of work to cover in short spaces of time. Hence, having individuals who have sufficient time to conduct important measures and analyse data effectively is of considerable benefit (Noon, 2016). Across the present project there were no restrictions (controls) in place that denied the players, performance and coaching staff access to the scores that were produced from growth, physical fitness and pitch-based exposure measurements. The testing was conducted to help guide interventions, give information to staff and players, whilst building rapport. However, scores for the psychological measures were kept confidential.

Since there are multiple aspects to injuries, it is important to include a variety of risk factors within any injury risk analysis (Bahr, and Holme, 2003). It could be determined that despite the high number of measures that have been included across the project to help identify injury risks there were a low number of significant findings. As well as traditional statistical approaches, more advanced data science approaches such as machine learning can be applied to examine injury risk (Rommers *et al*., 2020). These advanced data science approaches are considered to better integrate the complexity of injury events and such approaches can take into account the many variables and their interactions (Me and Unold, 2011; Rommers *et al*., 2020).

Machine learning approaches have been applied within footballers (youth and senior) for both large and small samples sizes and have successfully predicted injury risk with a high degree of accuracy (Rommers *et al*., 2020; Rossi *et al*., 2020). It is considered by Rommers and colleagues that incorporation of boosted regression tree models (machine learning) which target high classification accuracy in their research could be the reasoning behind differences between other studies' examinations of injury risk where no associations were demonstrated Similar findings were demonstrated between this project (Study 2) and the research conducted by Rommers and colleagues where a higher sit and reach score indicated potentially future injury risk (Rommers *et al*., 2020). Perhaps examining both machine learning and traditional statistical approaches together across the same data set would be insightful, however ideally this would incorporate a large subject cohort to increase statistical power for the traditional methods.

7.4 Practical implications

Currently, academies within the EPPP have access to a PMA which allows them to manage data of injury, growth, physical fitness, exposure and attendance to training sessions and matches (input, analyse and feedback) for registered players. Some organisations also utilise internal data management systems which can provide for daily monitoring of players using a holistic approach. As stated previously, the EPPP have set batteries of monitoring measures for neuromuscular physical fitness and growth development. It would be interesting to see whether implementation of further testing batteries conducted at particular time points during a playing season i.e., pre-season, post winter break and at the end of a season, which were specifically designed to help monitor physical strength and flexibility development, would be effective. For example, findings from the project indicate that non-contact injury i.e., HSI, and time lost from non-contact injury, can affect strength development, such as impaired eccentric hamstring strength and increased imbalances between limbs when jumping (Studies 1 and 3). This may further increase the risk to injury and impair physical development over a longitudinal period (Bourne *et al*., 2018). Therefore, observations of physical fitness of previously injured participants would be appropriate. Scrutinising player development post-injury, and if possible, during the rehabilitation processes, are considered imperative, as higher levels of physical strength are related to achieving an elite senior playing standard (Study 2) (Le Gall *et al*., 2010). Currently, testing batteries and pre-season screenings to determine injury risks are typically formulated from organisations' individual needs and determinations. More organisations are starting to implement the same testing measures such as the sit and reach test, NHE through use of the NordBord and vertical jump asymmetries through force plates (Lovell *et al*., 2019b). It may be insightful to give a layout and guidelines within a standardised operating procedure for testing protocols for a reliable testing battery for EPPP academies to implement, as well as specific ranges for each measure that could anticipate intrinsic injury risks and performance indicators for different age groups and positions. For example, Study 2 identified significantly higher sit and reach scores being a possible risk of low availability in training and matches from non-contact injury. Giving academies a range of specific flexibility tests, such as the sit and reach, in which hypermobile characteristics were evaluated alongside flexibility impairment (Witvrouw *et al.*, 2003; García-Pinillos *et al.*, 2015; Mills *et al.*, 2015; Hatano *et al.*, 2019), could help flag up possible risk of injury (Study 2). However, for some academies the equipment and software can be hard to acquire; for example, due to cost, so these batteries are unlikely to be enforced and may just be considered as guidelines.

As player data for injury, growth, physical fitness, exposure and attendance to training sessions and matches can be stored within the same data management system, examination of the interactions of these measures are possible, either within the data management system from specifically constructed algorithms or from external analysis from data export of raw files. If multiple academies utilised the same battery of monitoring measures to monitor injury risks, at the same time-points of the season, and data was effectively collected in the same fashion as the set EPPP growth and physical fitness testing batteries, observations could be made of the interactions between variables of injury frequency, growth, physical fitness and external (i.e., time motion analyses) and internal loads (i.e., HR monitoring, RPE) across multiple cohorts. In turn, with appropriate analysis, feedback of injury risks and player development from specific ranges of the measures could be calculated to help inform practitioners and coaches at academies and the EPPP. Having multiple academies using the same or a similar standard operating procedure in unison, and cumulatively over time, has the potential to increase the power of analysis of injury risk and development measures. This also allows findings to be specifically related to elite academy footballers and to specific age groups. In addition, progression through the age group squads, and attainment of professional contracts and progression to an elite senior standard could be assessed and compared against physical characteristics such as growth and physical fitness, similar to Study 2.

Difficulties can arise when applying monitoring measures whether they be new or already implemented within a weekly monitoring schedule. These include practitioners not having the time to plan, conduct and analyse data from measures as well the possibility of not understanding testing protocols and analysis prior to testing (Noon *et al.*, 2015). A solution to resolve these potential issues would be to either have a research team based within an organisation (Noon *et al.*, 2015), or have external support from individuals and their organisations who are adept with the testing protocols and have the necessary equipment. At set times during a season, researchers could assist practitioners with testing protocols and help guide the analysis outputs. Whether external support would permit the necessary personal rapport with youth footballers remains to be seen. However, additional support may help elevate some of the testing pressures and workload that is placed on practitioners.

7.5 Future research

The following research could be conducted to extend the findings on elite youth footballers reported within the present thesis:

- An interdisciplinary examination of the impact of non-contact injury utilising a repeated measures design over a longitudinal period using a multi-academy approach.
- Examination of biochemical measures such as testosterone, cortisol, testosterone/cortisol ratios (only *via* saliva) against physical and psychological stressors.

Future research could still incorporate longitudinal examinations employing monitoring measures covering injury occurrence, availability, growth, physical fitness, accumulated exposure and psychological and physical stress measures where appropriate. However, a different approach could be used. A repeated measures design could be employed to examine acute ‘daily’ or ‘weekly’ changes where more sensitive changes might be indicated (Brink *et al*., 2010) and could be compared against injury-occurrence of specific anatomical sites within an injury audit format (Read *et al*., 2018b; Tears, Chesterton and Wijnbergen, 2018). If measures are employed across a longitudinal period, then development changes can still be scrutinised against injury occurrence and levels of availability affected by injury in the same approach as followed within the present project.

For a repeated measures approach to be conducted, a larger participant cohort is necessary than that used in the present project. By incorporating participant cohorts from different EPPP academies a larger number of participants would be available for testing, but differences among academies would need to be controlled for. This would be best achieved by standardising testing measures (standard operating procedures) across academies. As well as a standardised administration of reliable protocols for a multi-academy study; facilities need to be in place to handle the large amount data collected. This includes additional controls for secure, limited researcher access. Such research should give academies valuable insight into which specific measures, and their score range, are more applicable to ascertain injury risks. Also, whether a player’s physical development characteristics are at, or below, the level of a player who is successful in progressing to a higher playing standard. The data may support a reduction in the extensive batteries of measures within an already busy weekly schedule and this may be possible for players within the same demographic.

When cardiovascular and neuroendocrine responses in the autonomic nervous system and hypothalamic-pituitary-adrenal axis are increased, they indicate a physiological reaction to physical and psychological stressors (Dickerson and Kemeny, 2004). Influences that affect reactivity to psychosocial stress include differences of exertion in physical activity, age, methods when testing and the type of stressor (Rimmele *et al*., 2007). Fitness capacity also has a bearing on the effect of psychological stressors with individuals demonstrating a greater aerobic capacity when exhibiting a lower state anxiety following exposure to a stressor (Rimmele *et al*., 2007). This hypothesis has also been supported by longitudinal studies, which have concluded that aerobic exercise initiates lower cardiovascular reactivity to psychological stressors (Spalding *et al*., 2004; Throne *et al*., 2000). From a football standpoint, aerobic exercise is a staple energy system utilised through physical exertion placed on the individual by the demands of the game (Bangsbo, Mohr and Krustrup, 2006). So, players with the exception of GKs are exposed to aerobic exercise on a cumulative basis. It is possible that exercise-induced adaptations may moderate responsiveness to other stressors, i.e. psychological stressors and that physical activity is associated with reduced adrenocortical, autonomic and psychological responses to the psychosocial stressor (Rimmele *et al*., 2007). The incidence of antagonistic health related functions has been linked to a manifestation of psychological distress (Perna and McDowell, 1995; Perna *et al*., 1998; Smith, Smoll and Ptacek, 1990; Smith, Smoll and Schutz, 1990; Williams and Andersen, 1998). Psychological distress, which is directed through cognitive-affective, behavioural and sympathoadrenal pathways, can intensify the symptoms of extended high-intensity and high-volume exercise (Perna *et al*., 1998; Williams and Andersen 1998), which elite youth footballers are required to complete (Read *et al*., 2018a and b).

The possible association between psychological stress and the variability in an athletes' endocrine and immune responses to exercise has been reviewed (Mackinnon, 1992). Research has shown biochemical variations (psychological mediated cortisol responses) including an increase in cortisol levels and decrease in immunoglobulin-A and testosterone levels. In turn, such hormonal changes could potentially increase the risk of viral illness and muscle catabolism through the course of a season with its cumulative effects (Lopez Calbet *et al*., 1993). Cortisol release is produced by activation of the hypothalamic pituitary adrenal cortex (HPAC) and its release appears reliant on cognitive appraisal or a stressor. Whilst cortisol secretion is appropriate for a stress response, the extended activation of the HPAC is harmful (McCabe and Schneiderman, 1985). Physical activity itself leads to catecholamine release *via* temporary sympathetic activation of the adrenal medulla. However, cortisol secretion *via* HPAC stimulation is reported to impact on self-appraised ability to control or cope with a stressor alongside intense physical activity (Frankenhaeuser, 1991). Work from Kirschbaum and colleagues stated that an adrenocortical reaction to mental stress is not reduced quickly in healthy participants. In high responders to stress, recurrent experiences of stress are likely to be linked with repeated high concentrations of cortisol secretions (Kirschbaum *et al*., 1995).

As demonstrated through the use of psychological measures, the only difference observed between levels of perceived stressors/ recovery-stress balances between participants who had lost a significant amount of training and match availability due to injury against those who did not was from Total Stress and Recovery (RESTQ-52). There are clear neuroendocrine responses in individuals exposed to levels of stressors deemed harmful or ‘physically’ taxing in nature (Rimmele *et al*., 2007), which again is highly likely to be relevant to elite footballers (Haugaasen and Jordet, 2012; Swainston, Wilson and Jones, 2020). Further examination would be insightful as to whether biochemical measures could anticipate levels of stress responses exhibited by players which would be concurrent with injury risk and reduced during physical development when injured. These biochemical exanimations could also indicate distinct signs of overtraining across a season (Urhausen and Kindermann, 2000) or could be applied to examine relationships with training and match performance exposure (Rowell *et al*., 2018).

7.6 Strengths and limitations

This research project had multiple strengths. It achieved the aim of establishing a testing design that could be incorporated within other similar football academy testing environments and from which the results may prove informative for players' development. All of the measures and testing protocols were field-based within an EPPP academy over longitudinal periods. Therefore, EPPP U16, U18 and U23 coaches and practitioners could replicate the testing protocols described within the project. The researcher (PhD student) was based full-time at the organisation where all of the testing procedures were conducted. Therefore, rapport was established ensuring clear communication with each participant. Testing procedures were controlled for, as much as possible, keeping the data collection standardised. The project explored the novel use of a wide, holistic range of physical measures typically implemented within current elite academy football (Lovell *et al*., 2019b) and compared them against HSI occurrence and reduced training and match availability due to sustaining a non-contact injury. Although, dependent on whether academies have the equipment available, specific monitoring practices such as examining eccentric knee flexor strength can be prescribed specifically for players returning from time-out from a HSI. Determining players' availability for training and matches, gives a comprehensive insight into the negative influence of injury on attendance. The large number of measures employed within the project could be considered as both a strength and a weakness. It demonstrates that a large number of measures can be employed successfully when a researcher is available at an academy and gives insight as to which variables could be beneficial for practitioners to examine further. However, it is considered that time available and feasibility for academies to apply testing measures may differ significantly (Rommers *et al*., 2020). It could be argued that the importance of injury research within elite football is vital, therefore if academies are able to invest successfully into injury research it would be a credible investment as the financial strain and consequences of missed development and competition of injury are significant. As stated previously, reporting relationships of various physiological and psychological measures against the influence of non-contact injury within an elite youth academy football cohort is a novel approach. Use of psychological measures incorporating the psychological factors from the Williams and Andersen model (Williams and Andersen, 2007) (Figures 2.3 and 6.1) within an EPPP cohort is also novel. The design of Study 3 allowed for multiple physical measures to be employed at both the start of the pre-season and competitive season, which allowed for greater insight into the influence of the pre-season on physiological adaptations.

Across the project performance staff at the organisation were not blinded to any of the physical scores collected from the participants involved. Additionally, performance staff at the organisation were not prevented from prescribing preventive measures to ‘at risk’ participants before they were exposed to any pitch-based exposure. Injury data included within the project was reliable and was set to specific classifications used within the literature (e.g., Price *et al*., 2004). Additionally, in Studies 2 and 3 measures were put in place to ensure there were no variations and errors in collection of injury data (Wik *et al*., 2019). Overuse injuries where players could have played through pain were not accounted for (Clarsen *et al*., 2015). Using a reduction process that removed some of the variables from the correlations within Studies 2 and 3 could result in some missed relationships. However, this approach was considered appropriate because of potential multicollinearity.

Some of the limitations within each study have already been identified within the individual chapters. As discussed previously, one overriding limitation is the cohort size and a strategic decision to alleviate this issue would be to recruit a higher number of participants of the same age range from numerous EPPP football academies to provide a large testing cohort. A multi-site study would help to reduce the influence of internal and external factors: access to training resources such as facilities and coaching; but would need to be consistent so as to provide one overarching testing environment for elite youth football testing. In addition, factors such as training and match demands and age range, as they relate specifically to various age groups within academy football, would need to be controlled.

Due to the nature of funding and stipulation the project was restricted to a single cohort of EPPP category 1 youth academy players from the same academy. Therefore, the data set could not be increased further. Additionally, the influence of internal factors within the project's testing environment, such as players having the same coaching and strength-based programming, should be considered. Such considerations would be important if the project's findings are to be applied to other testing environments, irrespective of whether or not, they are EPPP category 1 academies. The numbers of participants involved in the three studies meant the power of the analyses would be weaker in comparison to an analysis that involved higher participant numbers; higher numbers are not possible when the studies were based in a single academy. When measuring longitudinal changes, there were some missing data points for some of the participants involved (Study 1), which could not be controlled for. These occurred when participants were either called up permanently to older age groups within the academy, were unable to complete the season due to injury or illness, or when they had left the organisation. In each study, some measures could not be implemented consistently, as a consequence of factors in the testing environment that could not be controlled for.

All three studies within the thesis were designed to be strictly exploratory. This project has identified some novel and insightful findings, however the nature of the data sets for all three studies must be acknowledged. First, as explained all the studies observe an uncontrollable small sample size. Second, a large number of measures were incorporated and parametric analysis (independent *t*-tests) used to examine differences between injury groups (Studies 1 and 2). Tests were conducted without Bonferonni corrections to account for type 1 error. Although these corrections have been considered within some research examinations based on higher numbers (Bourne *et al*., 2016), application of such a correction would have been detrimental in the present project, as determination of significance would be difficult due to multiple measures being examined. Therefore, the findings produced from this project should be viewed with caution and not as conclusive.

Due to these strengths and limitations, the project offers a unique starting point to be progressed further with future examinations. Testing design constraints and complications have been recognised, and therefore can be built and mediated appropriately if possible. Overall, the current study should help to support others undertaking similar investigations in football academies.

7.7 Conclusions

The present research project focussed solely on footballers within a single EPPP academy environment and explored which physical and psychological measures were associated with HSI and the significant time lost to training and competition due to non-contact injury. At the same time the thesis also determined how sustaining a HSI and low availability for training and competition could in turn influence physical and psychological development at a critical stage in the players careers. Of the multiple measures employed, hypermobile characteristics and asymmetrical dominance when landing could indicate low availability for the remainder of a season. Also, when players are older, they are more likely to sustain a HSI, which can impair eccentric knee flexor strength and body mass gain. Although low availability can enable player to improve in some aspects of physical strength, they can adopt compensatory strategies to apply maximal force and their opportunities to be exposed to pitch-based physical demands are mitigated. Low availability can also influence a player's fluctuations in stress and recovery, and reduce their coping resources. Independent of injury, there are multiple relationships between components of growth, physical fitness, pitch-based exposure, and psychological factors, all of which are likely to interact; consequently, these components should not be considered in isolation. The thesis provides responses to each of the original aims. Whilst this project has identified some novel findings with elite youth footballers it is considered an observational exploratory starting point in which the research design can be built upon in the future. The monitoring approaches employed within the current research project could be used within academy football environments and the project's findings may give players, coaches, practitioners and researchers insights to help progress academy footballers to a higher playing standard and to investigate further.

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Appendix 1: Consent/assent forms

PARENTAL/GUARDIAN CONSENT FORM

Title of Project: **An interdisciplinary stress-based examination of injury occurrence in youth soccer players**

Name of Researcher: **Mr James Silver**

Names of supervisors: **Dr Morgan Williams, Prof Richard Mullen**

Please **initial** all boxes

1. I confirm that I have read and understand the parental information sheet Version 3. 14/02/18 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. I understand the principles, procedures and possible risks involved. ☐

2. I understand that my child's participation is voluntary and that I am free to withdraw consent for them to take part at any time without giving any reason, without any consequence to myself or my child. ☐

3. I agree to:
    - have my child's data, which is collected daily through the Academy to be accessed by the research team and used for this study; ☐
    - my child completing the psychological focused questionaires. ☐

4. I agree to my child's anonymised data being used in study specific reports and subsequent articles that will appear in academic journals. ☐

☐

5. I agree for my child to take part in the above study.

____________________	____________________	____________________
Name of Participant	Date	Signature
____________________	____________________	____________________
Name of Parent/Guardian	Date	Signature
____________________	____________________	____________________
Name of person - taking consent.	Date	Signature

University of South Wales
Prifysgol De Cymru

CONSENT FORM

Title of Project: **An interdisciplinary stress-based examination of injury occurrence in youth soccer players**

Name of Researcher: **Mr James Silver**

Names of supervisors: **Dr Morgan Williams, Prof Richard Mullen**

Please **initial** all boxes

1. I confirm that I have read and understand the information sheet Version 3. 14/02/18 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. I understand the principles, procedures and possible risks involved. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without any consequence to myself. ☐

3. I agree to:
   - have data, which is collected daily through the Academy to be accessed by the members of the research team and used in the study. ☐
   - complete psychological focused questionaires. ☐

4. I agree to my anonymised data being used in study specific reports and subsequent articles that will appear in academic journals. ☐

5. I agree to take part in the above study. ☐

University of South Wales
Prifysgol De Cymru

Name of Participant	Date	Signature
Name of person - taking consent.	Date	Signature

STUDY ASSENT FORM (under 18 year-olds)

Title of Project: **An interdisciplinary stress-based examination of injury occurrence in youth soccer players**

Name of Researcher: **Mr James Silver**

Names of supervisors: **Dr Morgan Williams, Prof Richard Mullen**

Please **initial** all boxes

6. I confirm that I have read and understand the information sheet Version 3. 14/02/18 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. I understand the principles, procedures and possible risks involved. ☐
7. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without any consequence to myself. ☐

1. I agree to my anonymised data being used in study specific reports and subsequent articles that will appear in academic journals. ☐

2. I agree to:

    - have data which is collected daily through the Academy to be accessed by the members of the research team and used in the study. ☐

    - Complete psychological focused questionaires. ☐

3. I agree to my anonymised data being used in study specific reports and subsequent articles that will appear in academic journals. ☐

4. I agree to take part in the above study. ☐

Name of Participant	Date	Signature
Name of person - taking consent.	Date	Signature

Appendix 1: Information sheets

Information Sheet

Parental Copy

Study Title: An interdisciplinary stress-based examination of injury occurrence in youth soccer players

Introduction

My name is James Silver a PhD student and a Sport Scientist at XXXXX Academy. Your child is being invited to take part in a research investigation. Before they take part, it is important for you both to understand why the research is being conducted and what will be required of your child should you agree for them to be involved. Please take time to read the following information carefully, and ask if there is anything that is not clear or if you would like more information. Please take your time to decide whether your child should take part.

What is the purpose of the study?

Availability, fitness, and readiness to perform to the highest level are all critical features for the development of Academy players. Academy Football has a relatively high injury incidence rate and playing time lost due to injury reduces the chances of any young player progressing and performing at the highest level. It is widely accepted that sports injuries are caused by a range of different factors. Identifying and monitoring risk factors and how they change during the season has become standard practice and may help guide Academy staff support the athletes under their care. Most of the monitoring systems focus on physical fitness few, if any include psychological factors. This addition may add value in monitoring and predicting injury.

Why has you child been invited?

Your child is a category one professional footballer and a member of the XXXXX Academy. Our study is looking at risk factors to youth footballers during the early stages of their careers. On a daily basis, they already complete a range of tests as part of the Academy's monitoring programme. They have been invited to take part in order to improve our monitoring and better predict those players at risk of injury.

Do they have to take part?

Your child will be given a similar information sheet to this one to read. Once they have read it and have taken time to consider if they are willing to taking part, they will be asked to provide assent if they agree**.** If they decide not to participate or withdraw during the study, their decision will not affect their relationship with the University, XXXXX

Academy or any of the investigators involved in the study. All of the psychological information collected during the study will be treated confidentially.

What will happen to them if they take part?

If your child decides to take part in the study they will be asked to complete three psychological questionnaires during the course of the season. These questionnaires are a measure of resilience and how young players cope with stresses of being a young professional player.

Expenses and payments

There will be no payments made to your child for taking part over the duration of the study.

What are the possible disadvantages and risks of taking part?

Completion of the questionnaires carries negligible risk of harm or distress for your child. The questions ask how they react and behave on a daily basis. If your child does want to speak with someone about any issues raised by the questionnaires, they can talk to anyone on the research team or if they prefer, they can contact Prof. David Shearer (email:), a HCPC registered sport psychologist who is not part of the research team. There is the possibility that they might disclose information that indicates harm to self, for example, coping by using alcohol or drugs. If players indicate this is the case we will refer them to the club's Education and Welfare Officer, who is equipped to deal with such issues.

What are the possible benefits of taking part?

We cannot promise that the study will help your child but the information we get from the study will help to increase our understanding of the factors that cause injury in Academy players.

What if there is a problem?

If you have a concern about any aspect of this study, feel free to speak or contact me () and I'll do my best to answer your questions. If you have questions regarding other problems you are free to contact the following members of the research team who will do their best to resolve any other possible issues.

Dr Morgan Williams:
Email:

Professor Rich Mullen (HCPC registered Sport Psychologist – PYL17462)
Email:

If they cannot resolve any possible issue you have had with the study and you remain unhappy you may contact the research governance officer, Mr Jonathan Sinfield.

Email:
Phone:

Will my child's participation be kept confidential?
Our procedures for handling, processing, storing and destruction of data match the Data Protection Act 1998. Your child's data will be collected using questionnaires. All of the information will be kept strictly confidential and any information about your child will not leave the University or the Academy.

What will happen if your child doesn't carry on with the study?
Please remember, if you decide that your child should not participate or withdraws during the study, your decision will not affect your or your child's relationship with myself, the University, XXXXX Academy or any other of the investigators involved in the study and there will be no consequences. Also, at any time you may withdraw consent for your child to be included in this study. They can also withdraw from this study if they wish at any time, without having to give any explanation and at no consequence to themselves. Should they be withdrawn from the study, all questionnaire data they have provided will be destroyed immediately.

What will happen to the results of the research study?
The results of the studies will be written up as a part of a PhD thesis. Also, we intend to publish a series of reports in a journal and present it at sport science conferences. When we do this the data will be aggregated and no individual player will be identifiable.

Who is organising or sponsoring the research?
This study is funded by the KESS Government fund and is organised through the University of South Wales in partnership with the XXXXX Academy.

Further information and contact details:
James Silver M.Sc.: XXXXX Academy Sports Scientist,
PhD Candidate
Faculty of Life Sciences and Education
University of South Wales
Email:

Thank you for taking the time to read this Information Sheet

Information Sheet

Participant Copy

Study Title: An interdisciplinary stress-based examination of injury occurrence in youth soccer players

Introduction

My name is James Silver a PhD student and a Sport Scientist at XXXXX Academy. You are being invited to take part in a research investigation. Before you take part, it is important for you to understand why the research is being conducted and what will be required of you should you agree to be involved. Please take time to read the following information carefully, and ask if there is anything that is not clear or if you would like more information. Please take your time to decide whether you should take part.

What is the purpose of the study?

Availability, fitness, and readiness to perform to the highest level are all critical features for the development of Academy players. Academy Football has a relatively high injury incidence rate and playing time lost due to injury reduces the chances of any young player progressing and performing at the highest level. It is widely accepted that sports injuries are caused by a range of different factors. Identifying and monitoring risk factors and how they change during the season has become standard practice and may help guide Academy staff support the athletes under their care. Most of the monitoring systems focus on physical fitness few, if any include psychological factors. This addition may add value in monitoring and predicting injury.

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Expenses and payments

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Email:

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Email:
Phone:

Will my participation be kept confidential?
Our procedures for handling, processing, storing and destruction of data match the Data Protection Act 1998. Your data will be collected using questionnaires. All of the information will be kept strictly confidential and any information about you will not leave the University or the Academy.

What will happen if you don’t carry on with the study?
Please remember, if you decide not to participate or withdraw during the study, your decision will not affect your relationship with myself, the University, XXXXX Academy or any other of the investigators involved in the study and there will be no consequences. Also, at any time you may withdraw consent to be included in this study. You can also withdraw from this study without having to give any explanation and at no consequence to yourself. Should you withdraw from the study, all questionnaire data provided will be destroyed immediately.

What will happen to the results of the research study?

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Further information and contact details:
James Silver M.Sc.: XXXXX Academy Sports Scientist,
PhD Candidate
Faculty of Life Sciences and Education
University of South Wales
Email:

Thank you for taking the time to read this Information Sheet

Appendix 2: Measures

Table 1. Details of growth measures commonly applied to elite youth footballers. Continued on following page.

Measure	Elite youth football use Participants (n); age (yrs), or age group	Equipment	Software	Viewpoint of measure	Variables obtained from the measure	Validation of measure	Reliability of measure
Body Mass*	Ryan *et al.*, 2018 n = 130; 13.8 ± 2.9 yrs	Body mass scale	n/a	Total body mass	Total body mass (kg)	Malina *et al.*, 2007	Buchheit and Mendez-Villanueva, 2013 Comparisons: n = 35; ICC = 1.00 (0.99; 1.00)
Stature*	Ryan *et al.*, 2018 n = 130; 13.8 ± 2.9 yrs	Stadiometer	n/a	Total body stature	Total body stature (cm)	Massard *et al.*, 2019 Comparisons: n = 38; Pearson correlation = 1.00 (0.99; 1.00)	Buchheit and Mendez-Villanueva, 2013 Comparisons: n = 35; ICC = 1.00 (0.99; 1.00)

Table 1. Details of growth measures commonly applied to elite youth footballers Continued**.**

Measure	**Elite youth football use** **Participants (n); age (yrs), or age group**	**Equipment**	**Software**	**Viewpoint of measure**	**Variables obtained from the measure**	**Validation of measure**	**Reliability of measure**
Seated stature*	Rommers *et al*., 2019 n = 619; U10 to U15	Stadiometer, growth and maturation box (height 40 cm)	n/a	Upper body stature & lower limb length	Upper body stature & lower limb length (cm)	Massard *et al*., 2019 Comparisons: n = 38; Pearson correlation = 1.00 (0.99; 1.00)	Massard *et al*., 2019 Comparisons: n = 38; ICC = 1.00 (0.99; 1.00)
Body fat measurements	Kemper *et a*l., 2015 n = 101; 11 to 19 yrs	Skinfold callipers	n/a	Body fat percentage estimations & equation	Skinfold 4, 7 or 8 sites (Right-hand side of body (total body fat score (%): biceps, triceps, subscapular and iliac crest & quadriceps, chest, calf (mm). Total body fat percentage (%)	Suarez-Arrones *et al*., 2018	Buchheit and Mendez-Villanueva, 2013

Measures labelled * were chosen to be applied within the project.
Reliability and validity are displayed for these measures from previous research. n, number (of participants); yrs, years; U, Under (age group); n/a, not applicable; kg, kilogramme; cm, centimetres; mm, millimetres; ICC, Intraclass correlation.

Table 2. Details of strength measures commonly applied to elite youth footballers. Continued on following pages.

Measure	Use in youth elite footballers Participants (n); age or age group	Equipment	Software, sample frequency (sf)	Viewpoint of measure	Variables obtained from measure	Validation of measure	Reliability of measure
Fixed dynamometry	Wollin, Purdam and Drew, 2016 n = 16; 16.81 ± 0.54 yrs	Fixed dynamometry	n/a	Isometric & eccentric force of the lower limbs e.g. quadriceps, hamstring, groin, hip	e.g., Peak isometric & eccentric force (N), difference between limbs (%)	Toonstra and Mattacola, 2013	Wollin, Purdam and Drew, 2016
Hand-held dynamometry	Wollin *et al*., 2018 n = 16; 15.53 ± 0.48 yrs	Hand-held dynamometry	n/a	Isometric & eccentric force of the lower limbs e.g. quadriceps, hamstring, groin, hip	e.g., Peak isometric force (N), difference between limbs (%)	Mentiplay *et al*., 2015	Fulcher, Hanna and Elley, 2010

Table 2. Details of strength measures commonly applied to elite youth footballers Continued.

Measure	**Use in youth elite footballers Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from measure**	**Validation of measure**	**Reliability of measure**
NHE *via* fixed load cells (NordBord)*	Fernandes *et al*., 2020 n = 64; 10 to 16 yrs	NordBord (VALD Performance, Albion, Queensland, Australia)	Scoreboard, (VALD Performance, Albion, Queensland, Australia); sf: 100 Hz	Eccentric hamstring strength from an NHE	e.g., Mean nordic force (N), nordic force between limbs (%)	Opar *et al*., 2013	Opar *et al*., 2013 Comparisons: n = 30; ICC = 0.83 to 0.90
Adductor strength *via* sphy at 45° hip flexion*	O'Brien, Santner and Finch, 2018 n = 58; 14 to 21 yrs	sphy (max reading 300 mmHg)	n/a	Isometric adductor strength from a short lever hip adduction position (at 45 ° hip flexion)	Maximum adductor force (mmHg)	Delahunt *et al*., 2011; Toohey *et al*., 2018 Comparisons: n = 32; (Pearson's r = 0.77 to 0.91)	O'Brien, Santner and Finch, 2018 Comparisons: n = 30; ICC = 0.91 (0.67 to 0.96)

Table 2. Details of strength measures commonly applied to elite youth footballers Continued.

Measure	**Use in youth elite footballers Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from measure**	**Validation of measure**	**Reliability of measure**
Adductor & abductor strength *via* external fixed dynamometry (GroinBar) at 60º & 90º hip flexion*	O'Brien *et al.*, 2019 Total n = 67, AFL n = 36, footballers n = 31; 20.1 ± 3.40 yrs	GroinBar and adjustable rig fitted with 4 independent, adjustable custom-made uniaxial load cells (VALD Performance, Albion, Queensland, Australia)	(Scoreboard, VALD Performance, Albion, Queensland, Australia); sf: 50 Hz	Isometric adductor & abductor strength from a short lever hip adduction position (at 60º & 90º hip flexion)	e.g., Mean adductor & abductor force (N), adductor force differences between limbs (%)	O'Brien *et al.*, 2019 Comparisons: n = 67; (Spearman's Rank Correlation Coefficient R_s = 0.53 to 0.71)	Ryan *et al.*, 2019 Comparisons: n = 18; ICC = 0.94

Table 2. Details of strength measures commonly applied to elite youth footballers Continued.

Measure	**Use in youth elite footballers Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from measure**	**Validation of measure**	**Reliability of measure**
CMJ *via* dual force platforms*	Poulson, 2017 n = 16; 19.8 ± 3.8 yrs	PASCO^{TM} dual force platforms PS-2141 (PASCO^{TM}, Roseville, California, USA)	NMP Force Decks^{TM} (London, UK; VALD Performance, Albion, Queensland, Australia) software; sf: 1,000 Hz	Unilateral neuromuscular lower limb power, concentric & eccentric force.	e.g., Concentric mean force (N), eccentric mean force (N), jump height (cm), peak force (N), concentric mean force asymmetry (%), eccentric mean force asymmetry (%)	Lake *et al*., 2016 (Reactive strength, force time characteristics) Comparisons: n = 21, (r = 0.99 to 1.00) (Jump height) Comparisons: n = 29, (r = 0.99)	Read *et al*., 2016; Poulson, 2017; Comparisons: n =16; Cronbach's α = 0.79

Measures labelled * were applied within the project. Reliability and validity are displayed for these measures from previous research.

CMJ, countermovement jump; NHE, Nordic Hamstring Exercise; n, number (of participants); yrs, years; AFL, Australian football league; n/a, not applicable; sphy**,** Sphygmomanometer; Hz, Hertz; sf, sample frequency; N, Newtons; ICC, Intraclass correlation

T**able 3. Details of flexibility measures commonly applied to elite youth footballers.** Continued on following pages.

Measure	**Use in youth elite footballers** **Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from the measure**	**Validation of measure**	**Reliability of measure**
Dorsiflexion lunge*	Bowen *et al*., 2019 n = 21; 15.7 ± 0.9 yrs	Tape measure	n/a	Indirect method: Ankle dorsiflexion flexibility	Unilateral ankle dorsiflexion range (cm)	Hall and Docherty (2017). Validity of clinical outcome measures to evaluate ankle ROM during the weight-bearing lunge test. Comparisons: n = 50; r = 0.74 (p = 0.001)	Konor *et al*., 2012 (Left limb) Comparisons: n = 20; ICC = 0.99 (0.98 to 1.00) (Right limb) Comparisons: n = 20; ICC = 0.98 (0.96 to 0.99)

Table 3. Details of flexibility measures commonly applied to elite youth footballers Continued.

Measure	**Use in youth elite footballers Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from the measure**	**Validation of measure**	**Reliability of measure**
Sit and reach test*	Kirkini *et al*., 2019 n = 103; U15, U17, U19 National team members	Sit and reach test testing box	n/a	Indirect method: Hamstring and lower back extensors flexibility	Sit and reach range (cm)	(Ayala *et al*., 2012a and b; Lemmink *et al*., 2003) Reproducibility and criterion-related validity of the sit and reach test and toe touch test for estimating hamstring flexibility in recreationally active young adults. Comparisons: n = 243; (R2 = 0.63)	Gabbe *et al*., 2004 Comparisons: n = 15; ICC = 0.63 to 0.99
Straight leg raise	Rolls and George, 2004 n = 111; 9 – 19 yrs	Goniometer	n/a	Direct method: Unilateral hamstring and lower back extensors flexibility	Straight leg raise range of separate limbs (cm)	Ayala *et al*., 2012a and b	Gabbe *et al*., 2004

Table 3. Details of flexibility measures commonly applied to elite youth footballers. Continued.

Measure	**Use in youth elite footballers Participants (n); age or age group**	**Equipment**	**Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from the measure**	**Validation of measure**	**Reliability of measure**
Functional Movement Screen (FMS) (straight leg raise)	Ryan *et al*., 2018 n = 130; 13.8 ± 2.9 yrs	Official FMS test kit was used (Functional Movement Systems Inc., USA).	n/a	Direct method: Unilateral hamstring and lower back extensors flexibility	Flexibility score 0 to 3	Cook *et al*., 2014a and b	Teyhen *et al*., 2012
Hip extension	Wollin *et al*., 2018 n = 16; 15.81 ± 0.65 yrs	Goniometer	n/a	Direct method: Unilateral external hip flexibility	Hip extension range of motion $^{(o)}$	Dennis *et al*., 2008	Gabbe *et al*., 2004
Knee extension	Wollin *et al*., 2018 n = 16; 15.81 ± 0.65 yrs	Electro-goniometer	n/a	Direct method: Unilateral flexibility of knee extension	Knee extension range of motion $^{(o)}$	Rowe *et al*., 2001	Gabbe *et al*., 2004

Measures labelled* were applied within the project.

Table 4 Details of external load measures commonly applied to elite youth footballers. Continued on following page.

Measure	**Use in youth elite footballers Participants (n); age or age group**	**Equipment** **Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from measure**	**Validation of measure**	**Reliability of measure**
Monitoring of external load velocities *via* internal tri-axial accelerometer, gyroscope, magnetometer, and satellite-based positioning system	Kovács *et al.*, 2020 n = 112; U17	GPS device (firmware version v727, OptimEye S5/ X4 (Catapult sports, Melbourne, Australia) Openfield software (Catapult sports, Melbourne, Australia) sf: 10 Hz engine accelerometers/ magnetometers sf: 100 Hz default	Time-motion variables covered within training sessions and matches	e.g., Total distance (m), high speed running (m), explosive distance (m), total PlayerLoad (au), number of sprints, sprint distance (m)	Nicolella *et al.*, 2018; Roe *et al.*, 2017	Nicolella *et al.*, 2018 Comparisons: n = 19; CV ranged from 0.01% to < 3.0% ICC ranged from 0.77 (95% CI: 0.62 to 0.89) (very large) to 1.0 (95% CI: 0.99 to 1.0)

Table 4. Details of external load measures commonly applied to elite youth footballers. Continued.

Measure	**Use in youth elite footballers Participants (n); age or age group**	**Equipment** **Software, sample frequency (sf)**	**Viewpoint of measure**	**Variables obtained from measure**	**Validation of measure**	**Reliability of measure**
Monitoring of external load velocities *via* internal tri-axial accelerometer, gyroscope, magnetometer and satellite-based positioning system	Lovell *et al*., 2019a n = 278; U15	GPS device OptimEye X4 (Catapult sports, Melbourne, Australia) Openfield software (Catapult sports, Melbourne, Australia) sf: 10 Hz engine accelerometers/ magnetometers sf: 100 Hz default	Time-motion variables covered within pitch-based training sessions and matches	e.g., Total distance (m), high speed running (m), explosive distance (m), total PlayerLoad (au), number of sprints, sprint distance (m)	Johnston *et al*., 2014; Weaving *et al*., 2017	Johnston *et al*., 2014 Comparisons: n = 8; ($p = 0.05$) (% TEM = 1.3%)

Measures labelled * were applied within the project. GPS, Global positioning system; n, number (of participants); m, metres; U, under (age group); n/a, not applicable; sf, sample frequency; Hz, Hertz; s, seconds; au, measurement of load; CV, coefficient of variation; ICC, intraclass correlation, CI, confidence interval; and TEM, Typical error of measurement

Table 5. RST-PQ Development and validation descriptive statistics and scale correlations Taken from Corr and Cooper (2016).

	1	2	3a	3b	3c	3d
1. FFFS		0.44	-0.08	-0.07	0.21	0.16
2. BIS		-	-0.06	-0.06	0.16	0.17
3. BAS						
3a. Reward interest			-	0.41	0.48	0.43
3b. Goal-drive persistence				-	0.33	0.02
3c. Reward Reactivity					-	0.42
3d. Impulsivity						-
Mean	24.07	56.00	18.48	21.23	28.62	19.82
SD	6.22	13.54	3.91	4.34	4.88	4.64
Min	10.00	25.00	7.00	7.00	10.00	8.00
Max	40.00	92.00	28.00	28.00	40.00	32.00
Skewness	0.17	0.25	0.00	-0.43	-0.28	0.09
Kurtosis	-0.58	-0.42	-0.22	-0.38	-0.22	-0.42
Alpha	0.78	0.93	0.75	0.86	0.78	0.74

FFFS, Fight-flight-freeze system; BIS, Behavioural inhibition system; BAS, Behavioural approach system.

Table 6. Day to day trial mean and internal consistency for the 19 scales on the recovery-stress questionnaire for sport (RESTQ-Sport). Taken from Noon (2016).

Scale	Trial 1	Trial 2	Trial 3	Cronbach α
General stress	0.52 ± 0.88	0.46 ± 0.68	0.63 ± 0.98	0.95
Emotional stress	1.17 ± 1.05	0.96 ± 0.89	0.90 ± 1.06	0.97
Social stress	1.38 ± 0.97	1.19 ± 1.15	1.48 ± 1.18	0.92
Conflicts / pressure	1.92 ± 0.99	1.48 ± 0.75	1.60 ± 0.90	0.91
Fatigue	1.44 ± 0.72	1.46 ± 0.73	1.50 ± 1.07	0.87
Lack of energy	1.44 ± 1.06	1.19 ± 0.82	1.37 ± 1.10	0.91
Physical complaints	1.58 ± 1.03	1.17 ± 1.00	1.15 ± 1.03	0.95
Success	3.21 ± 0.75	2.81 ± 0.77	3.00 ± 0.80	0.87
Social recovery	4.02 ± 1.14	3.92 ± 0.96	3.85 ± 1.02	0.84
Physical recovery	3.37 ± 0.95	3.13 ± 1.00	3.21 ± 1.22	0.92
General well-being	3.35 ± 0.75	3.44 ± 0.82	3.19 ± 0.85	0.81
Sleep Quality	4.21 ± 1.15	3.85 ± 1.20	3.77 ± 1.10	0.9
Disturbed breaks	1.12 ± 0.95	0.94 ± 0.65	0.98 ± 0.91	0.9
Emotional exhaustion	1.06 ± 0.78	1.08 ± 0.81	0.90 ± 0.81	0.96
Injury	2.19 ± 1.21	2.02 ± 1.31	2.19 ± 1.16	0.92
Being in shape	3.40 ± 1.09	3.48 ± 0.98	3.21 ± 0.78	0.85
Personal accomplishment	2.87 ± 1.13	2.88 ± 1.36	2.83 ± 1.45	0.94
Self-efficacy	3.42 ± 1.02	3.23 ± 0.91	3.29 ± 0.98	0.9
Self-regulation	3.60 ± 1.39	3.35 ± 1.20	3.21 ± 1.29	0.88

Trial data are expressed as mean ± SD. Internal consistency assessed using Cronbach's

Table 7. Interfactor correlation matrix and Cronbach's α reliability for the Brief COPE. Taken from Dias, Cruz and Fonseca (2009).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1													
2	.14**	1												
3	.20***	.06	1											
4	.09*	-.14**	.19***	1										
5	.20***	.18***	.22***	.08	1									
6	.20***	.30***	.16***	.02	.72***	1								
7	.12**	-.18***	.24***	.23***	.08	-.001	1							
8	.24***	.25***	.25***	.11**	.27***	.30***	.04	1						
9	.18***	.38***	.09*	.03	.11*	.17***	-.05	.23***	1					
10	.12**	.43***	.09*	-.001	.14**	.22***	-.10*	.30***	.49***	1				
11	.20***	.14**	.11*	.13**	.09*	.15***	-.001	.20***	.36***	.27***	1			
12	.14**	.28***	.001	.008	.08	.19***	-.03	.24***	.34***	.35***	.24***	1		
13	.13**	.23***	.18***	.11**	.23***	.25***	.01	.29***	.27***	.22***	.12**	.15***	1	
14	.13**	.13**	.18***	.17***	.14***	.16***	.19***	.32***	.15**	.26***	.15***	.21***	.21***	1
α	.48	.41	.55	.73	.80	.73	.75	.32	.65	.55	.82	.57	.76	.60

1-Self-distraction; 2-Active coping; 3-Denial; 4-Substance use; 5-Emotional support; 6-Instrumental support;7-Behavioural disengagement; 8-Venting of emotions; 9-Positive reframing; 10-Planning; 11-Humour;12-Acceptance; 13- Religion;14-Self-blame. *$p < 0.05$; **$p < .01$; ***$p < .001$.

Appendix 2: Statistical analyses for Studies (1, 2 and 3)

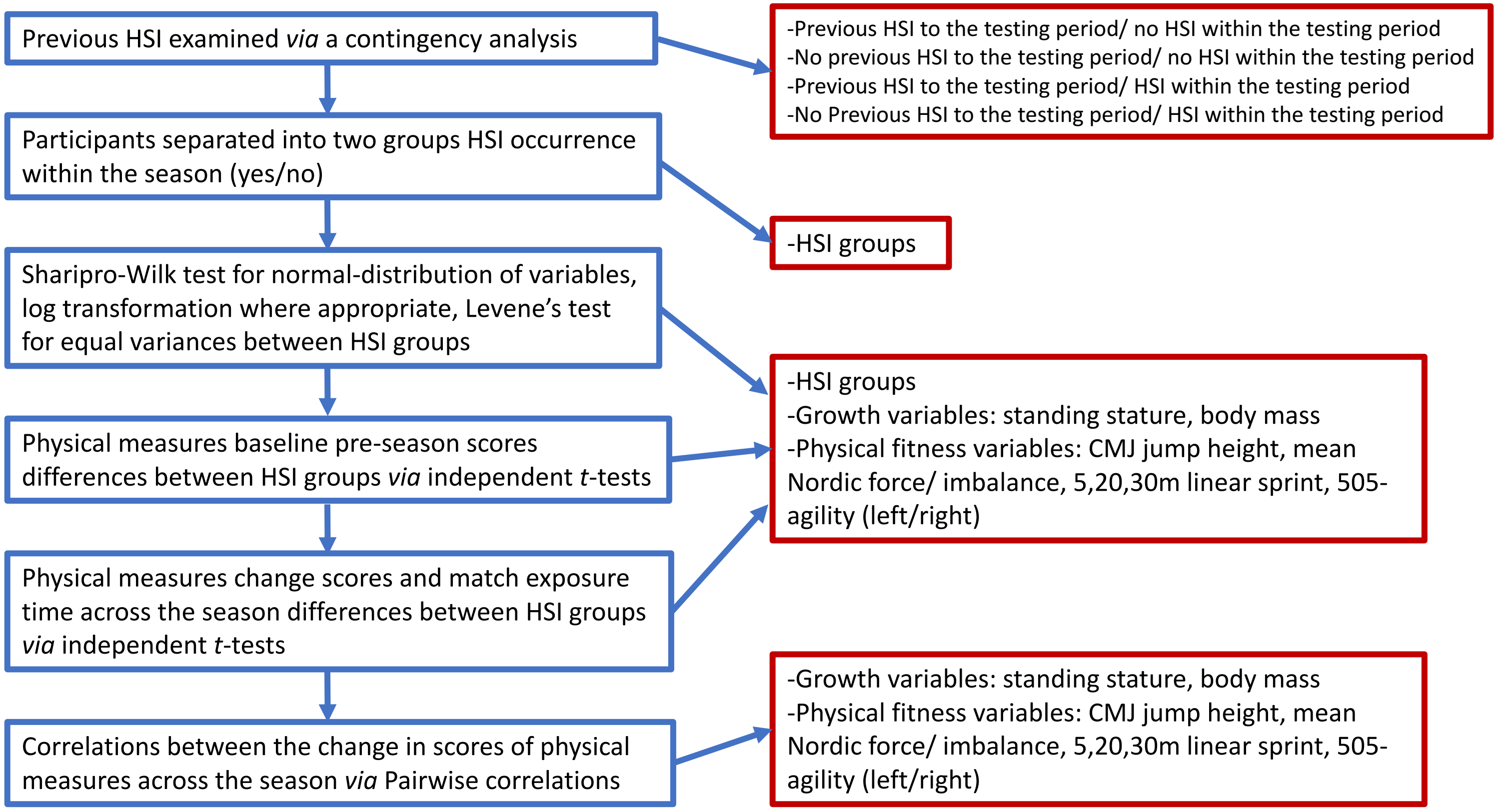


Figure 1. Flow chart of statistical analyses for Study 1. Blue tables display each of the stages involved within the statistical analysis and red tables display each of the variables involved. Blue arrows indicate which variables were utilised within each stage of analysis.

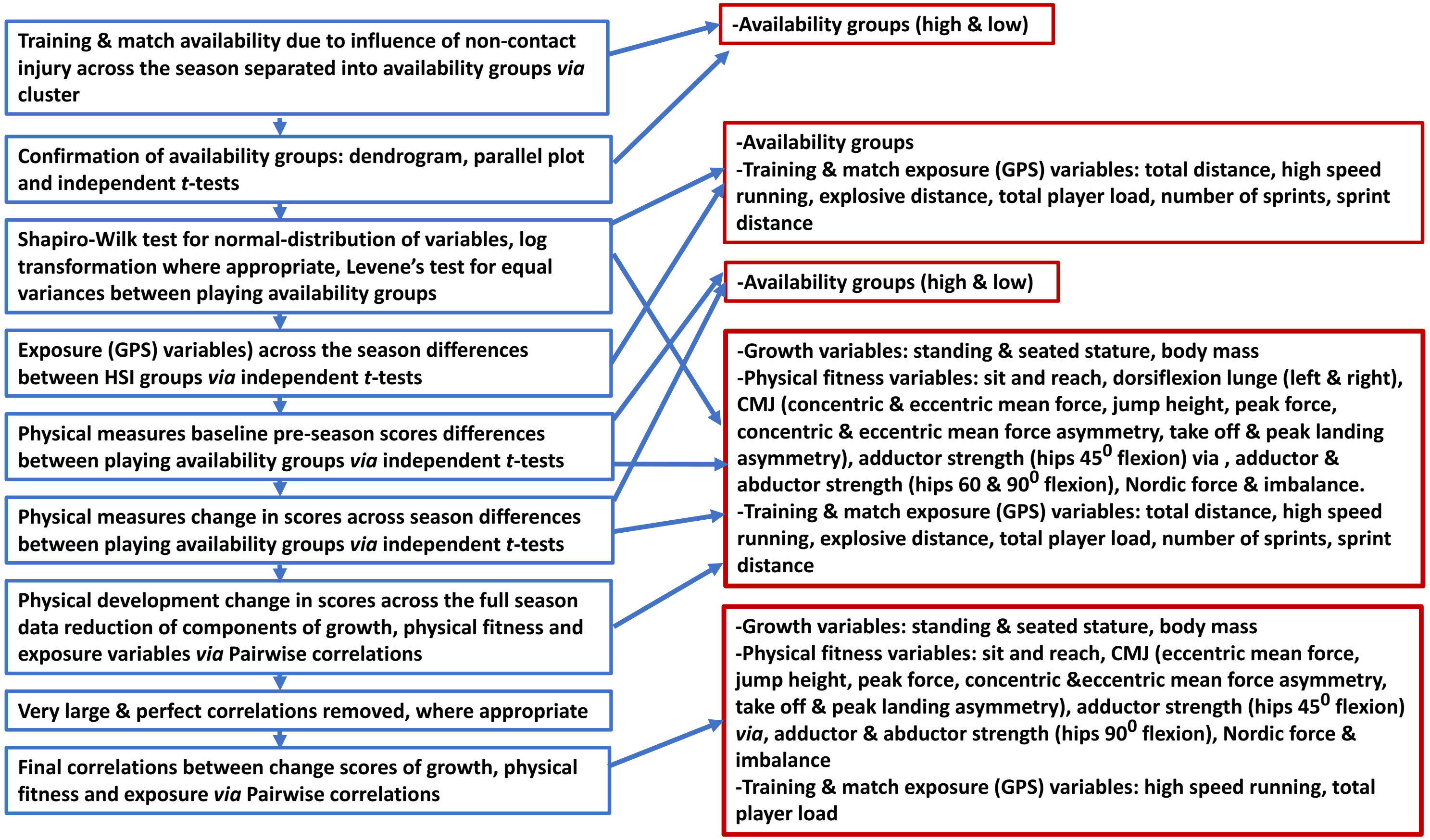


Figure 2. Flow chart for the statistical analyses for Study 2. Blue tables display each of the stages involved within the statistical analysis and red tables display each of the variables involved. Blue arrows indicate which variables were utilised within each stage of analysis

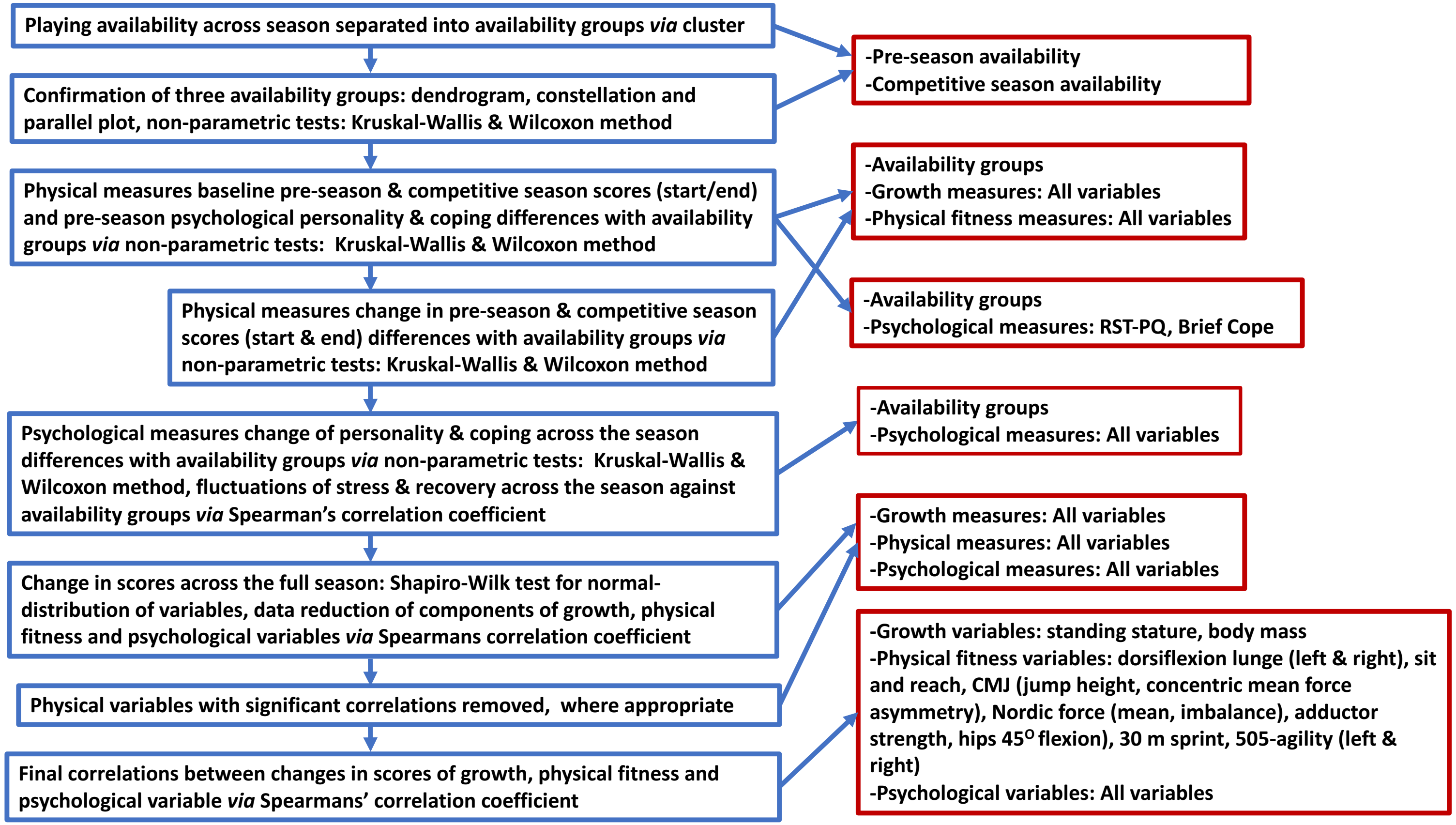


Figure 3. Flow chart for the statistical analyses for Study 3. Blue tables display each of the stages involved within the statistical analysis and red tables display each of the variables involved. Blue arrows indicate which variables were utilised within each stage of analysis

Table 8. Pairwise correlations of physical fitness development variables from Study 2. Continued on following page.

Variable comparison	Sit and reach (cm)	CMJ: eccentric mean force (N)	CMJ: jump height (cm)	CMJ: peak force log transformation data (N)	CMJ: concentric mean force asymmetry (%)	CMJ: eccentric mean force asymmetry (%)	CMJ: take off peak force asymmetry (%)	CMJ: peak landing force asymmetry (%)	Nordic mean force (N)	Nordic imbalance (%)	Adductor strength mean force 60^0 flexion (N)	Adductor strength imbalance 60^0 flexion (%)	Adductor strength mean force 90^0 flexion (N)	Adductor strength imbalance 90^0 flexion (%)	Abductor strength mean 60^0 force (N)	Abductor strength imbalance 60^0 flexion (%)	Abductor strength mean force 90^0 flexion (N)	Abductor strength imbalance 90^0 flexion (%)
Sit and reach (cm)	n/a	-0.07	0.12	0.14	-0.09	0.23	0.04	0.03	0.13	-0.05	0.22	-0.05	0.21	-0.05	0.26	-0.15	0.07	0.14
CMJ: eccentric mean force (N)	-0.07	n/a	0.08	0.13	**-0.33^**	0.22	-0.05	-0.21	**0.36^**	**0.36^**	-0.16	0.10	**0.45^**	**0.38^**	0.19	**0.33^**	**0.48^**	**0.32^**
CMJ: jump height (cm)	0.12	0.08	n/a	**0.57^^**	-0.07	0.06	**0.42^**	**-0.33^**	**0.39^**	**0.40^**	-0.26	0.29	0.10	-0.04	**0.40^**	0.00	-0.19	-0.05
CMJ: peak force log transformation data (N)	0.14	0.13	**0.57^^**	n/a	0.07	0.24	**0.44^**	**-0.46^**	0.11	**0.37^**	0.13	-0.01	**0.33^**	-0.02	**0.60^^**	0.24	0.00	0.11
CMJ: concentric mean force asymmetry (%)	-0.09	**-0.33^**	-0.07	0.07	n/a	**-0.35^**	**0.61^^**	0.02	0.07	-0.10	0.27	**0.32^**	**0.30^**	-0.15	0.15	-0.10	**0.39^**	**0.41^**
CMJ: eccentric mean force asymmetry (%)	0.23	0.22	0.06	0.24	**-0.35^**	n/a	-0.18	-0.12	-0.18	-0.03	-0.16	**-0.47^**	-0.14	0.16	**-0.51^**	-0.07	**-0.46^**	**-0.44^**
CMJ: take off peak force asymmetry (%)	0.04	-0.05	**0.42^**	**0.44^**	**0.61^^**	-0.18	n/a	-0.09	0.12	0.12	**0.31^**	-0.22	**0.39^**	0.15	**0.64^^**	0.12	**0.63^^**	**0.51^^**
CMJ: peak landing force asymmetry (%)	0.03	-0.21	**-0.33^**	**-0.46^**	0.02	-0.12	-0.09	n/a	**-0.48^**	**-0.57^^**	-0.13	0.15	**-0.35^**	-0.15	**-0.38^**	-0.11	-0.20	-0.21
Nordic mean force (N)	0.13	**0.36^**	**0.39^**	0.11	0.07	-0.18	0.12	**-0.48^**	n/a	**0.57^^**	0.23	0.15	**0.52^^**	**0.45^**	**0.45^**	**-0.61^^**	**0.54^^**	0.25
Nordic imbalance (%)	-0.05	**0.36^**	**0.40^**	**0.37^^**	-0.10	-0.03	0.12	**-0.57^^**	**0.57^^**	n/a	0.20	-0.13	**0.48^**	**0.41^**	0.26	-0.17	**0.51^^**	**0.59^^**

Table 8. Pairwise correlations of physical fitness development variables from Study 2. Continued.

Variable comparison	Sit and reach (cm)	CMJ: eccentric mean force (N)	CMJ: jump height (cm)	CMJ: peak force log transformation data (N)	CMJ: concentric mean force asymmetry (%)	CMJ: eccentric mean force asymmetry (%)	CMJ: take off peak force asymmetry (%)	CMJ: peak landing force asymmetry (%)	Nordic mean force (N)	Nordic imbalance (%)	Adductor strength mean force 60^0 flexion (N)	Adductor strength imbalance 60^0 flexion (%)	Adductor strength mean force 90^0 flexion (N)	Adductor strength imbalance 90^0 flexion (%)	Abductor strength mean 60^0 force (N)	Abductor strength imbalance 60^0 flexion (%)	Abductor strength mean force 90^0 flexion (N)	Abductor strength imbalance 90^0 flexion (%)
Adductor strength *via* GB mean force 60^0 flexion (N)	0.22	-0.16	-0.26	0.13	0.27	-0.16	**0.31**^	-0.13	0.23	0.20	n/a	**-0.62**^	**0.65**^^	-0.34	**0.70**^^^	**-0.41**^^	**0.71**^^^	-0.06
Adductor strength *via* GB imbalance 60^0 flexion (%)	-0.05	0.10	0.29	-0.01	**0.32**^	**-0.47**^^	-0.22	0.15	0.15	-0.13	**-0.46**^^	n/a	**-0.67**^^	0.27	-0.26	0.16	-0.31	-0.02
Adductor strength *via* GB mean force 90^0 flexion (N)	0.21	**0.45**^^	0.10	**0.33**^	**0.30**^	-0.14	**0.39**^	**-0.35**^	**0.52**^^	**0.48**^	**0.65**^^	**-0.67**^^	n/a	-0.13	**0.35**^	**-0.37**^	**0.60**^^	0.21
Adductor strength *via* GB imbalance 90^0 flexion (%)	-0.05	**0.38**^	-0.04	-0.02	-0.15	0.16	0.15	-0.15	**0.45**^	**0.41**^	-0.34	0.27	-0.13	n/a	-0.08	0.07	0.14	**0.49**^^
Abductor strength *via* GB mean force 60^0 flexion (N)	0.26	0.19	**0.40**^	**0.60**^^	0.15	**-0.51**^^	**0.64**^^	**-0.38**^	**0.45**^	0.26	**0.70**^^^	-0.26	**0.35**^	-0.08	n/a	**-0.47**^	**0.57**^^	-0.30
Abductor strength *via* GB imbalance 60^0 flexion (%)	-0.15	**0.33**^	0.00	0.24	-0.10	-0.07	0.12	-0.11	**-0.61**^^	-0.17	**-0.41**^	0.16	**-0.37**^	0.07	**-0.47**^	n/a	-0.20	0.38
Abductor strength *via* GB mean force 90^0 flexion (N)	0.07	**0.48**^	-0.19	0.00	**0.39**^	**-0.46**^	**0.63**^^	-0.20	**0.54**^^	**0.51**^^	**0.71**^^^	**-0.31**^	**0.60**^^	0.14	**0.57**^	-0.20	n/a	**0.51**^
Abductor strength *via* GB imbalance 90^0 flexion (%)	0.14	**0.32**^	-0.05	0.11	**0.41**^	**-0.44**^	**0.51**^^	-0.21	0.25	**0.59**^	-0.06	-0.02	0.21	**0.49**^	-0.30	0.38	**0.51**^	n/a

Degrees (^{0}) of flexion for adductor and abductor strength refers to flexion of the hip; sphy, Sphygmomanometer; GB, GroinBar; CMJ, counter movement jump; transform, transformed. All correlations above ≥0.30 were highlighted in bold. All correlations labelled ^ had a correlation ≥0.30, all correlations labelled ^^ had a correlation ≥ 0.50, all correlations labelled ^^^ had a correlation ≥ 0.70.

Table 9. Pairwise correlations of physical development and exposure variables from Study 2. Continued on following page.

Variable comparison	Body mass (kg)	Standing stature (cm)	Seated stature (cm)	Sit and reach (cm)	CMJ: eccentric mean force (N)	CMJ: jump height (cm)	CMJ: peak force log transform data (N)	CMJ: concentric mean force asymmetry (%)	CMJ: eccentric mean force asymmetry (%)	CMJ: take off peak force asymmetry (%)	CMJ: peak landing force asymmetry (%)	Adductor strength via GB 90^0 flexion (N)	Adductor strength imbalance via GB 90^0 flexion (%)	Abductor strength mean force via GB 90^0 flexion (N)	Abductor strength imbalance via GB 90^0 flexion (%)	Nordic force (N)	Nordic force imbalance (%)	Training total player load (au)	Training high speed running (m)	Match total player load (au)	Match high speed running (m)
Body mass (kg)	n/a	**0.32**^	0.16	**0.49**^	0.07	0.10	0.09	0.04	0.19	-0.07	-0.14	**0.31**^	0.29	0.26	0.44	0.48	0.12	-0.17	-0.18	-0.11	0.03
Standing stature (cm)	**0.32**^	n/a	**0.52**^^	0.17	0.19	0.00	0.00	0.09	-0.10	-0.04	0.19	0.22	0.26	0.00	-0.24	**0.46**^	-0.03	0.15	0.00	-0.08	-0.06
Seated stature (cm)	0.16	**0.52**^^	n/a	0.20	**0.63**^^	0.22	0.18	0.04	**0.34**^	0.29	0.13	0.19	0.18	**0.38**^	0.04	**0.52**^^	0.20	0.25	-0.05	**0.34**^	-0.03
Sit and reach (cm)	**0.49**^	0.17	0.20	n/a	-0.07	0.12	0.14	-0.09	0.23	0.04	0.03	0.21	-0.05	0.07	0.14	0.13	-0.05	0.28	0.03	0.27	0.11
CMJ: eccentric mean force (N)	0.07	0.19	**0.63**^^	-0.07	n/a	0.08	0.13	**-0.33**^	0.22	-0.05	-0.21	**0.45**^	**0.38**^	**0.48**^	**0.32**^	**0.36**^	**0.36**^	**0.33**^	0.07	**0.36**^	0.01
CMJ: jump height (cm)	0.10	0.00	0.22	0.12	0.08	n/a	**0.57**^^	-0.07	0.06	**0.42**^	**-0.33**^	0.10	-0.04	-0.19	-0.05	**0.39**^	**0.40**^	**0.62**^^	**0.44**^	**0.46**^	0.12
CMJ: peak force log transform data (N)	0.09	0.00	0.18	0.14	0.13	**0.57**^^	n/a	0.07	0.24	**0.44**^	**-0.46**^	**0.33**^	-0.02	0.00	0.11	0.11	**0.37**^	**0.52**^^	0.05	**0.35**^	**-0.31**^
CMJ: concentric mean force asymmetry (%)	0.04	0.09	0.04	-0.09	**-0.33**^	-0.07	0.07	n/a	**-0.35**^	**0.61**^^	0.02	**0.30**^	-0.15	**0.39**^	**0.41**^	0.07	-0.10	-0.04	-0.07	0.12	0.18
CMJ: eccentric mean force asymmetry (%)	0.19	-0.10	**0.34**^	0.23	0.22	0.06	0.24	**-0.35**^	n/a	-0.18	-0.12	-0.14	0.16	**-0.46**^	**-0.44**^	-0.18	-0.03	-0.22	-0.46	-0.10	**-0.48**^
CMJ: take off peak force asymmetry (%)	-0.07	-0.04	0.29	0.04	-0.05	**0.42**^	**0.44**^	**0.61**^^	-0.18	n/a	-0.09	**0.39**^	0.15	**0.63**^^	**0.51**^^	0.12	0.12	**0.50**^^	**0.43**^	**0.50**^^	**0.40**^
CMJ: peak landing force asymmetry (%)	-0.14	0.19	0.13	0.03	-0.21	**-0.33**^	**-0.46**^	0.02	-0.12	-0.09	n/a	**-0.35**^	-0.15	-0.20	-0.21	**-0.48**^	**-0.57**^^	-0.15	-0.03	0.28	**0.38**^

Table 9. Pairwise correlations of physical development and exposure variables from Study 2. Continued.

Variable comparison	Body mass (kg)	Standing stature (cm)	Seated stature (cm)	Sit and reach (cm)	CMJ: eccentric mean force (N)	CMJ: jump height (cm)	CMJ: peak force log transform data (N)	CMJ: concentric mean force asymmetry (%)	CMJ: eccentric mean force asymmetry (%)	CMJ: take off peak force asymmetry (%)	CMJ: peak landing force asymmetry (%)	Adductor strength via GB 90^0 flexion (N)	Adductor strength imbalance via GB 90^0 flexion (%)	Abductor strength mean force via GB 90^0 flexion (N)	Abductor strength imbalance via GB 90^0 flexion (%)	Nordic force (N)	Nordic force imbalance (%)	Training total player load (au)	Training high speed running (m)	Match total player load (au)	Match high speed running (m)
Adductor strength via GB 90^0 flexion (N)	0.31	0.22	0.19	0.21	**0.45**^	0.10	**0.33**^	**0.30**^	-0.14	**0.39**^	**-0.35**	n/a	-0.13	**0.60**^^	0.21	**0.52**^^	**0.48**^	**0.67**^^	0.25	**0.51**^^	0.17
Adductor strength imbalance via GB 90^0 flexion (%)	0.29	0.26	0.18	-0.05	**0.38**^	-0.04	-0.02	-0.15	0.16	0.15	-0.15	-0.13	n/a	0.14	**0.49**^	**0.45**^	**0.41**^	-0.12	0.11	-0.21	0.06
Abductor strength mean force via GB 90^0 flexion (N)	0.26	0.00	**0.38**^	0.07	**0.48**^	-0.19	0.00	**0.39**^	**-0.46**^	**0.63**^^	-0.20	**0.60**^^	0.14	n/a	**0.51**^^	**0.54**^^	**0.51**^^	**0.56**^^	**0.47**^	**0.51**^^	**0.46**^
Abductor strength imbalance via GB 90^0 flexion (%)	**0.44**^	-0.24	0.04	0.14	**0.32**^	-0.05	0.11	**0.41**^	**-0.44**^	**0.51**^^	-0.21	0.21	**0.49**^	**0.51**^^	n/a	0.25	**0.59**^^	-0.06	0.06	0.05	0.25
Nordic force (N)	**0.48**^	**0.46**^	**0.52**	0.13	**0.36**^	**0.39**^	0.11	0.07	-0.18	0.12	**-0.48**^	**0.52**^^	**0.45**^	**0.54**^^	0.25	n/a	**0.57**^^	**0.38**^	**0.33**^	0.16	0.09
Nordic force imbalance (%)	0.12	-0.03	0.20	-0.05	**0.36**^	**0.40**^	**0.37**^	-0.10	-0.03	0.12	**-0.57**^^	**0.48**^	**0.41**^^	**0.51**^^	**0.59**^^	**0.57**^^	n/a	**0.33**^	0.09	0.04	**-0.30**^
Training total player load (au)	-0.17	0.15	0.25	0.28	**0.33**^	**0.62**^^	**0.52**^^	-0.04	-0.22	**0.50**^^	-0.15	**0.67**^^	-0.12	**0.56**^^	-0.06	**0.38**^	**0.33**	n/a	**0.74**^^	**0.76**^^	**0.44**^^
Training high speed running (m)	-0.18	0.00	-0.05	-0.03	0.07	**0.44**^	0.05	-0.07	**-0.46**^	**0.43**^	-0.03	0.25	0.11	**0.47**^	0.06	**0.33**^	0.09	**0.74**^^	n/a	**0.46**^	**0.74**^^
Match total player load (au)	-0.11	-0.08	**0.34**^	0.27	**0.36**^	**0.46**^	**0.35**^	0.12	-0.10	**0.50**^^	0.28	**0.51**^^	-0.21	**0.51**^^	0.05	0.16	0.04	**0.76**^^	**0.46**^	n/a	**0.57**^^
Match high speed running (m)	0.03	-0.06	-0.03	0.11	0.01	0.12	**-0.31**^	0.18	**-0.48**^	**0.40**^	**0.38**^	0.17	0.06	**0.46**^	0.25	0.09	**-0.30**^	**0.44**^	**0.74**^^	**0.57**^^	n/a

Degrees (^{0}) of flexion for adductor and abductor strength refers to flexion of the hip; sphy, Sphygmomanometer; GB, GroinBar; CMJ, counter movement jump; transform, transformed. All correlations above ≥ 0.30 were highlighted in bold. All correlations labelled ^ had a correlation ≥ 0.30, all correlations labelled ^^ had a correlation ≥ 0.50, all correlations labelled ^^^ had a correlation ≥ 0.70

Table 10. Significant individual Pairwise correlations between physical development and exposure from Study 2.

Variable comparison				
Variable 1	**Variable 2**	**Correlation**	**95% Confidence interval**	**[1]*p*-value**
Sit and reach (cm)	Body mass (kg)	0.49	0.1123 to 0.7479	0.0143*
CMJ: eccentric mean force (N)	Seated stature (cm)	0.63	0.192 to 0.8569	0.0092**
CMJ: eccentric mean force asymmetry (%)	Match high speed running	-0.48	-0.7676 to -0.345	0.0370*
CMJ: take off peak force asymmetry (%)	Match total PlayerLoad (au)	0.50	0.0631 to 0.7791	0.00282**
CMJ: take off peak force asymmetry (%)	Training total PlayerLoad (au)	0.50	-0.0582 to 0.7772	0.0296*
Nordic force (N)	Body mass (kg)	0.48	0.0126 to 0.7718	0.0455*
Nordic force (N)	Seated stature (cm)	0.52	0.0056 to 0.8135	0.0487*
Training total PlayerLoad (au)	CMJ: jump height (cm)	0.62	0.2373 to 0.8402	0.0043**
Training total PlayerLoad (au)	CMJ: peak force (N)§	0.52	0.0816 to 0.7864	0.0235*
Training total PlayerLoad (au)	Adductor strength 90^{0}	0.67	0.1521 to 0.8976	0.0177*
Match total PlayerLoad (au)	CMJ: jump height (cm)	0.46	0.0063 to 0.7558	0.048*

[1] All significant *p*-values are labelled accordingly: < 0.05* and < 0.01**; § log transformed.

Table 11. Significant individual *p*-values of personality and coping.

	Baseline scores		Change scores	
Variables	**Chi Square (χ^2)**	**[1] *p*-value**	**Chi Square (χ^2)**	**[1] *p*-value**
RST-PQ				
Fight-flight-freeze system	0.8579	0.6512	2.1200	0.3465
Behavioural inhibition system	0.1506	0.9275	1.1368	0.5664
Behavioural approach system	1.9271	0.3815	0.2989	0.8612
Defensive fight	1.3201	0.5168	4.8293	0.0894
Brief COPE				
Self-distraction	0.7584	0.6844	0.3543	0.8376
Active coping	2.0861	0.3524	8.3305	0.0155*
Denial	4.9532	0.0840	1.9860	0.3705
Substance use	1.0833	0.5818	1.9961	0.3686
Use of emotional support	1.8308	0.4004	2.6772	0.2622
Use of instrumental support	2.6128	0.2708	1.8031	0.4059
Behavioural disengagement	1.7313	0.4208	0.9479	0.6225
Venting	0.2790	0.8698	0.3925	0.8218
Positive reframing	1.6609	0.4358	7.6824	0.0215*
Planning	4.9015	0.0862	3.4025	0.1825
Humour	2.6333	0.2680	0.4202	0.8105
Acceptance	0.3219	0.8513	0.9058	0.6358
Religion	1.2864	0.5256	0.0633	0.9688
Self-blame	0.9303	0.6280	0.3670	0.8324

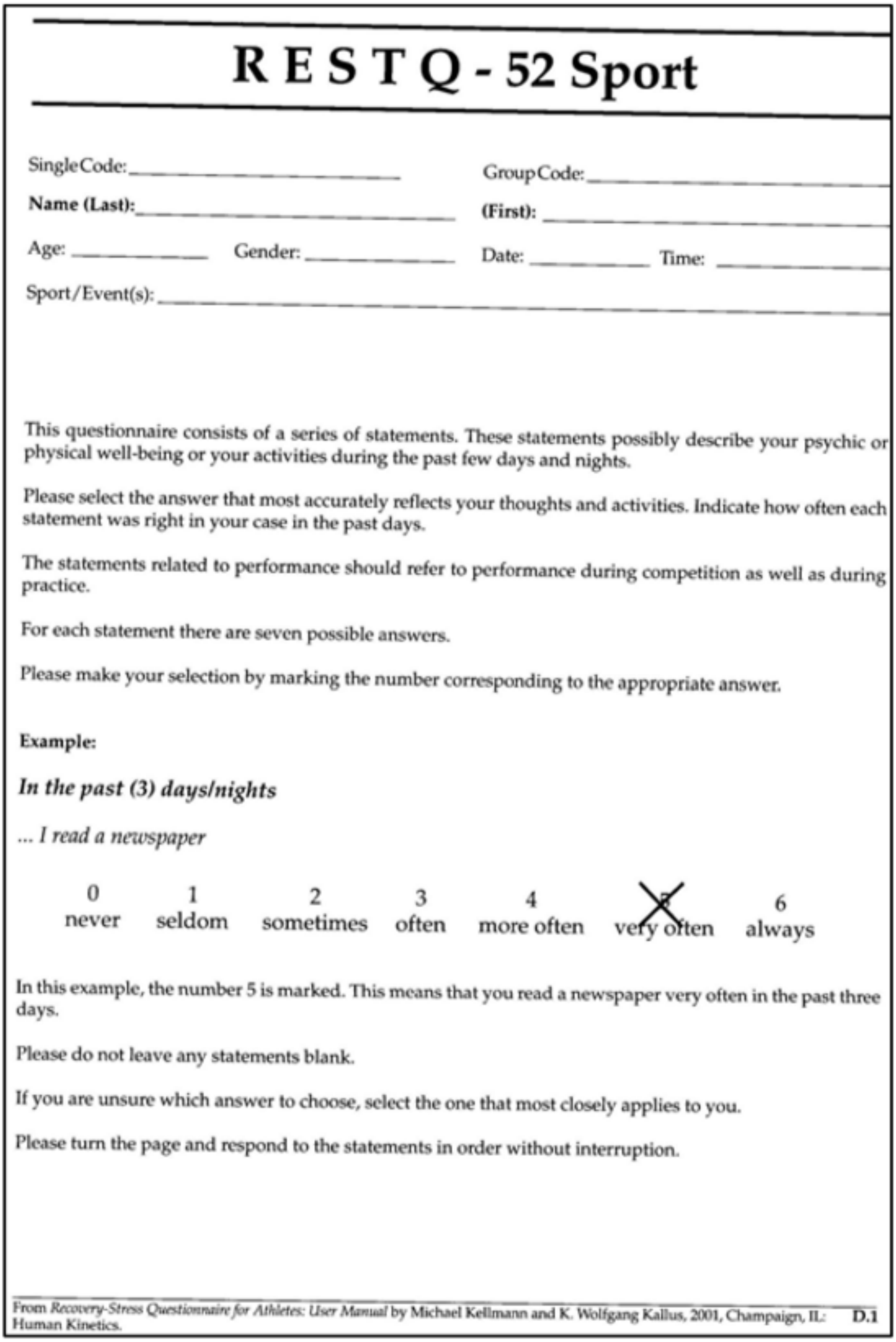
[1] All significant *p*-values are labelled accordingly: ≤ 0.05*. RST-PQ, The Reinforcement sensitivity theory of personality questionnaire.

Appendix 3: Psychological measures

The following psychological questionnaires were used to determine history of stressors, personality, and coping and were completed at the end of the EPPP 2017-18 season and throughout the EPPP 2018-19 season. These questionnaires were completed individually in the presence of the researcher, who was available to answer any questions. When completing each questionnaire, participants were unable to communicate with any individual other than the researcher. Participants were free to withdraw from each testing session if they wished, or if they did not feel comfortable, and they did not have to complete every item. The items and scoring of each questionnaire remained confidential. Displayed below are the items within each of the questionnaires and how items were scored accordingly into sub-scales.

History of stressors

The following questionnaire shows the items that were administered for the Recovery-Stress Questionnaire for Athletes (RESTQ-52-R-Sport) (Kellmann and Kallus, 2001) which reviewed participants' stress and recovery status.



R E S T Q - 52 Sport

Single Code: ______________________

Group Code: ______________________

Name (Last): ______________________

(First): ______________________

Age: __________ Gender: __________ Date: __________ Time: __________

Sport/Event(s): ______________________

This questionnaire consists of a series of statements. These statements possibly describe your psychic or physical well-being or your activities during the past few days and nights.

Please select the answer that most accurately reflects your thoughts and activities. Indicate how often each statement was right in your case in the past days.

The statements related to performance should refer to performance during competition as well as during practice.

For each statement there are seven possible answers.

Please make your selection by marking the number corresponding to the appropriate answer.

Example:

In the past (3) days/nights

... I read a newspaper

0	1	2	3	4	[✓ 5]	6
never	seldom	sometimes	often	more often	[✓ very often]	always

In this example, the number 5 is marked. This means that you read a newspaper very often in the past three days.

Please do not leave any statements blank.

If you are unsure which answer to choose, select the one that most closely applies to you.

Please turn the page and respond to the statements in order without interruption.

From *Recovery-Stress Questionnaire for Athletes: User Manual* by Michael Kellmann and K. Wolfgang Kallus, 2001, Champaign, IL: Human Kinetics. **D.1**

In the past (3) days/nights

1)… *I watched TV*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

2)… *I Laughed*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

3)… *I was in a bad mood*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

4)… *I felt physically relaxed*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

5)… *I was in good spirits*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

6)… *I had difficulties in concentrating*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

7)… *I worried about unresolved problems*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

8)… *I had a good time with my friends*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

9)… *I had a headache*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

10)… *I was dead tired after work*
0 1 2 3 4 5 6
never seldom sometimes often more often very often always

11)… *I was successful in what I did*
0 1 2 3 4 5 6
never seldom sometimes often more often very often always

12)… *I felt uncomfortable*
0 1 2 3 4 5 6
never seldom sometimes often more often very often always

13)… *I was annoyed by others*
0 1 2 3 4 5 6
never seldom sometimes often more often very often always

14)… *I felt down*
0 1 2 3 4 5 6
never seldom sometimes often more often very often always

15)… *I had a satisfying sleep*
0 1 2 3 4 5 6
never seldom sometimes often more often very often always

16)… *I was fed up with everything*
0 1 2 3 4 5 6
never seldom sometimes often more often very often always

17)… *I was in a good mood*
0 1 2 3 4 5 6
never seldom sometimes often more often very often always

18)… *I was over tired*
0 1 2 3 4 5 6
never seldom sometimes often more often very often always

In the past (3) days/nights

19)… *I slept restlessly*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

20)… *I was annoyed*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

21)… *I felt as if I could get everything done*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

22)… *I was upset*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

23)… *I put off making decisions*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

24)… *I made important decisions*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

25)… *I felt under pressure*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

26)… *parts of my body were aching*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

27)… *I could not get rest during the breaks*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

28)… *I was convinced I could achieve my set goals during performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

29)… *I recovered well physically*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

30)… *I felt burned out by my sport*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

31)… *I accomplished many worthwhile things in my sport*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

32)… *I prepared myself mentally for performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

33)… *my muscles felt stiff or tense during performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

34)… *I had the impression there were too few breaks*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

35)… *I was convinced that I could achieve my performance at any time*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

36)… *I dealt very effectively with my teammates' problems*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

37)… *I was in a good condition physically*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

38)… *I pushed myself during performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

39)… *I felt emotionally drained from performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

40)… *I had muscle pain after performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

41)… *I was convinced that I performed well*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

42)… *too much was demanded of me*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

43)… *I psyched myself up before performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

44)… *I felt that I wanted to quit my sport*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

45)… *I felt very energetic*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

46)… *I easily understood how my teammates felt about things*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

47)… *I was convinced that I had trained well*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

48)… *the breaks were not at the right times*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

49)… *I felt vulnerable to injuries*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

50)… *I set definite goals for myself during performance*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

51)… *my body felt strong*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

52)… *I felt frustrated by my sport*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

53)… *I dealt with emotional problems in my sport very calmly*

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

Thank you very much!

Scales and items of the RESTQ-52 Sport

From Recovery Stress Questionnaire for Athletes: User Manual by Michael Kellmann and K. Wolfgang Kallus 2001, Champaign, IL. Human Kinetics.

Scale 1: General Stress
14) I felt down
16) I was fed up with everything

Scale 2: Emotional Stress
3) I was in a bad mood
20) I was annoyed

Scale 3: Social Stress
13) I was annoyed by others
22) I was upset

Scale 4: Conflicts/Pressures
7) I worried about unresolved problems
25) I felt under pressure

Scale 5: Fatigue
10) I was dead tired after work
18) I was overtired

Scale 6: Lack of energy
6) I had difficulties in concentrating
23) I put off making decisions

Scale 7: Somatic Complaints
9) I had a headache
12) I felt uncomfortable

Scale 8: Success
11) I was successful in what I did
24) I made important decisions

Scale 9: Social Relaxation
2) I laughed
8) I had a good time with my friends

Scale 10: Somatic Relaxation
4) I felt physically relaxed
21) I felt as if I could get everything done

Scale 11: General Well-being
5) I was in good spirits
17) I was in a good mood

Scale 12: Sleep Quality
15) I had a satisfying sleep
19) I slept restlessly

Scale 13: Disturbed breaks
27) I could not get rest during breaks
34) I had the impression there were too few breaks
42) Too much was demanded of me during the breaks
48) The breaks were not at the right times

Scale 14: Burnout/Emotional Exhaustion
30) I felt burned out by my sport
39) I felt emotionally drained from performance
44) I felt that I wanted to quit my sport
52) I felt frustrated by my sport

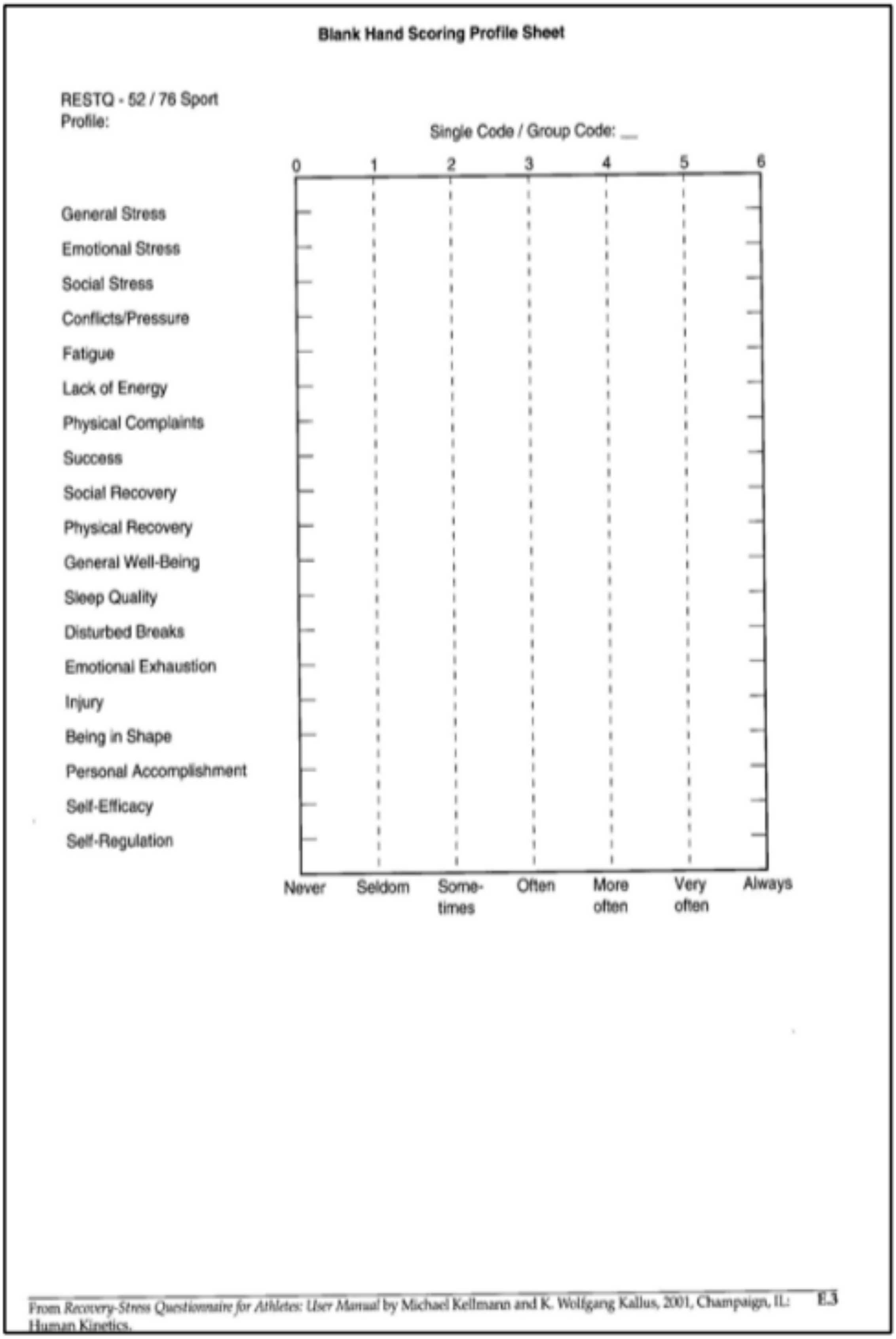
Scale 15: Fitness/Injury
26) parts of my body were aching
33) my muscles felt stiff or tense during performance
40) I had muscle pain after performance
49) I felt vulnerable to injuries

Scale 16: Fitness/Being in Shape
29) I recovered well physically
37) I was in a good condition physically
45) I felt very energetic
51) my body felt strong

Scale 17: Burnout/Personal Accomplishment
31) I accomplished many worthwhile things in my sport
36) I dealt very effectively with my teammates' problems
46) I easily understood how my teammates felt about things
53) I dealt with emotional problems in my sport very calmly

Scale 18: Self-Efficacy
28) I was convinced I could achieve my set goals during performance
35) I was convinced that I could achieve my performance at any time
41) I was convinced that I performed well
47) I was convinced that I had trained well

Scale 19: Self-Regulation
32) I prepared myself mentally for performance
38) I pushed myself during performance
43) I psyched myself up before performance
50 I set definite goals for myself during performance



Blank Hand Scoring Profile Sheet

RESTQ - 52 / 76 Sport
Profile:

Single Code / Group Code: __

0 1 2 3 4 5 6

General Stress
Emotional Stress
Social Stress
Conflicts/Pressure
Fatigue
Lack of Energy
Physical Complaints
Success
Social Recovery
Physical Recovery
General Well-Being
Sleep Quality
Disturbed Breaks
Emotional Exhaustion
Injury
Being in Shape
Personal Accomplishment
Self-Efficacy
Self-Regulation

Never Seldom Some-times Often More often Very often Always

From *Recovery-Stress Questionnaire for Athletes: User Manual* by Michael Kellmann and K. Wolfgang Kallus, 2001, Champaign, IL: Human Kinetics.

E.3

Personality

The Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ) was developed by Corr and Cooper (2016). Below are the listed items of the RST-PQ which were administered in this project.

University of South Wales Personality Profile

Instructions

Below is a list of statements about everyday feelings and behaviours. Please rate how accurately each statement describes *you in general*. Circle only one response. Do not spend too much time thinking about the questions and please answer honestly. Your answers will remain anonymous and confidential.

	How accurately does each statement describe *you*?	**Response**			
		Not at all	**Slightly**	**Moderately**	**Highly**
1	I feel sad when I suffer even minor setbacks.	1	2	3	4
2	I am often preoccupied with unpleasant thoughts.	1	2	3	4
3	Sometimes even little things in life can give me great pleasure.	1	2	3	4
4	I am especially sensitive to reward.	1	2	3	4
5	I put in a big effort to accomplish important goals in my life.	1	2	3	4
6	I sometimes feel ‘blue’ for no good reason.	1	2	3	4
7	When feeling ‘down’, I tend to stay away from people.	1	2	3	4
8	I often experience a surge of pleasure running through my body.	1	2	3	4
9	I would be frozen to the spot by the sight of a snake or spider.	1	2	3	4
10	I have often spent a lot of time on my own to “get away from it all”.	1	2	3	4
11	I am a very active person.	1	2	3	4
12	I’m motivated to be successful in my personal life.	1	2	3	4
13	I am always ‘on the go’.	1	2	3	4
14	I regularly try new activities just to see if I enjoy them.	1	2	3	4
15	I get carried away by new projects.	1	2	3	4

16	Good news makes me feel over-joyed.	1	2	3	4
17	The thought of mistakes in my work worries me.	1	2	3	4
18	When nervous, I sometimes find my thoughts are interrupted.	1	2	3	4
19	I would run quickly if fire alarms in a shopping mall started ringing.	1	2	3	4
20	I often overcome hurdles to achieve my ambitions.	1	2	3	4
21	I often feel depressed.	1	2	3	4
22	I think I should ‘stop and think’ more instead of jumping into things too quickly.	1	2	3	4
23	I often feel that I am on an emotional ‘high’.	1	2	3	4
24	I love winning competitions.	1	2	3	4
25	I get a special thrill when I am praised for something I’ve done well.	1	2	3	4
26	I take a great deal of interest in hobbies.	1	2	3	4
27	I sometimes cannot stop myself talking when I know I should keep my mouth closed.	1	2	3	4
28	I often do risky things without thinking of the consequences.	1	2	3	4
29	My mind is sometimes dominated by thoughts of the bad things I’ve done.	1	2	3	4
30	I get very excited when I get what I want.	1	2	3	4
31	I feel driven to succeed in my chosen career.	1	2	3	4

32	I’m always finding new and interesting things to do.	1	2	3	4
33	I’m always weighing-up the risk of bad things happening in my life.	1	2	3	4
34	People are often telling me not to worry.	1	2	3	4
35	I am very open to new experiences in life.	1	2	3	4
36	I always celebrate when I accomplish something important.	1	2	3	4
37	I find myself reacting strongly to pleasurable things in life.	1	2	3	4
38	I find myself doing things on the spur of the moment.	1	2	3	4
39	I would instantly freeze if I opened the door to find a stranger in the house.	1	2	3	4
40	I’m always buying things on impulse.	1	2	3	4
41	I am very persistent in achieving my goals.	1	2	3	4
42	When trying to make a decision, I find myself constantly chewing it over.	1	2	3	4
43	I often worry about letting down other people.	1	2	3	4
44	I would go on a holiday at the last minute.	1	2	3	4
45	I would run fast if I knew someone was following me late at night.	1	2	3	4
46	I would leave the park if I saw a group of dogs running around barking at people.	1	2	3	4
47	I worry a lot.	1	2	3	4

48	I would freeze if I was on a turbulent aircraft.	1	2	3	4
49	My behaviour is easily interrupted.	1	2	3	4
50	It’s difficult to get some things out of my mind.	1	2	3	4
51	I think the best nights out are unplanned.	1	2	3	4
52	There are some things that I simply cannot go near.	1	2	3	4
53	If I see something I want, I act straight away.	1	2	3	4
54	I think it is necessary to make plans in order to get what you want in life.	1	2	3	4
55	When nervous, I find it hard to say the right words.	1	2	3	4
56	I find myself thinking about the same thing over and over again.	1	2	3	4
57	I often wake up with many thoughts running through my mind.	1	2	3	4
58	I would not hold a snake or spider.	1	2	3	4
59	Looking down from a great height makes me freeze.	1	2	3	4
60	I often find myself ‘going into my shell’.	1	2	3	4
61	My mind is dominated by recurring thoughts.	1	2	3	4
62	I am the sort of person who easily freezes-up when scared.	1	2	3	4
63	I take a long time to make decisions.	1	2	3	4
64	I often find myself lost for words.	1	2	3	4

65	I will actively put plans in place to accomplish goals in my life.	1	2	3	4
66	I usually react immediately if I am criticised at work.	1	2	3	4
67	I have found myself fighting back when provoked.	1	2	3	4
68	I think retaliation is often the best form of defence.	1	2	3	4
69	I think you have to stand up to bullies in the workplace.	1	2	3	4
70	I would defend myself if I was falsely accused of something.	1	2	3	4
71	If I feel threatened, I will fight back.	1	2	3	4
72	I would not tolerate bullying behaviour towards me.	1	2	3	4
73	I can be an aggressive person when I need to be.	1	2	3	4

Coping

Brief COPE (Carver *et al*., 1997).

Brief COPE

These items deal with ways you've been coping with the stress in your life. There are many ways to try to deal with problems. These items ask what you've been doing to cope. Obviously, different people deal with things in different ways, but I'm interested in how you've tried to deal with it. Each item says something about a particular way of coping. I want to know to what extent you've been doing what the item says. How much or how frequently. Don't answer on the basis of whether it seems to be working or not—just whether or not you're doing it. Use these response choices. Try to rate each item separately in your mind from the others. Make your answers as true FOR YOU as you can.

1 = I haven't been doing this at all
2 = I've been doing this a little bit
3 = I've been doing this a medium amount
4 = I've been doing this a lot

1. I've been turning to work or other activities to take my mind off things.
2. I've been concentrating my efforts on doing something about the situation I'm in.
3. I've been saying to myself "this isn't real.".
4. I've been using alcohol or other drugs to make myself feel better.
5. I've been getting emotional support from others.
6. I've been giving up trying to deal with it.
7. I've been taking action to try to make the situation better.
8. I've been refusing to believe that it has happened.
9. I've been saying things to let my unpleasant feelings escape.
10. I’ve been getting help and advice from other people.
11. I've been using alcohol or other drugs to help me get through it.
12. I've been trying to see it in a different light, to make it seem more positive.
13. I’ve been criticizing myself.

14. I've been trying to come up with a strategy about what to do.
15. I've been getting comfort and understanding from someone.
16. I've been giving up the attempt to cope.
17. I've been looking for something good in what is happening.
18. I've been making jokes about it.
19. I've been doing something to think about it less, such as going to movies, watching TV, reading, daydreaming, sleeping, or shopping.
20. I've been accepting the reality of the fact that it has happened.
21. I've been expressing my negative feelings.
22. I've been trying to find comfort in my religion or spiritual beliefs.
23. I’ve been trying to get advice or help from other people about what to do.
24. I've been learning to live with it.
25. I've been thinking hard about what steps to take.
26. I’ve been blaming myself for things that happened.
27. I've been praying or meditating.
28. I've been making fun of the situation.