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Monitoring in Elite Youth Soccer: Describing Load, Reducing Data and Assessing its Relationship with Physical Fitness Outcomes

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A thesis submitted in fulfilment of the
requirements for the degree of

Doctor of Philosophy (Sport and Exercise)

Under the supervision of:

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Certificate of Original Authorship

I, Darragh Robert Connolly declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy (Sport and Exercise), in the Faculty of Health at the University of Technology Sydney. This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used is indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program and the Juventus Football Club (Italy).

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Preface

This thesis for the degree of Doctor of Philosophy is in the format of Thesis by Compilation following the ‘Graduate Research Candidature Management, Thesis Preparation and Submission Procedures’.

The current thesis presents a collective body of studies that are published or prepared for submission in scientific journals. Study one is accepted and published in the Journal of Strength and Conditioning Research. Studies three to six are currently in preparation for journal submission. This thesis contains a general introduction that details the background to load monitoring in team sports and the importance of this process in youth soccer before stating the key objectives for each study (chapter one). A systematic review is included to provide a comprehensive overview of the current evidence as it relates to the relationship between training dose and the outcome response to training in elite youth soccer players (chapter two). The main body of research is presented in chapters three to seven, in the form of six original investigations. Collectively, these studies combine to describe the load performed by elite youth-level soccer players and establish the constructs of load that describe the greatest amount of variance within a player monitoring dataset. The general discussion provides an interpretation of the studies from a practical standpoint and details clear implications for sports scientists and researchers working in the elite youth football academies. The final section of this thesis provides an interpretation of the collective findings and suggests practical recommendations that help to guide areas that researchers can further investigate. All references are included in the reference list at the end of the thesis.

Finally, the impact of the COVID-19 pandemic should also be acknowledged. Specifically, the prolonged lockdown periods, inability to travel internationally, the new work organization at Juventus (i.e., COVID bubbles, etc.), and increased work demands required to manage these factors severely affected the original research.

List of Publications

Peer-reviewed journal articles

Connolly, D.R., Stolp, S., Gualtieri, A., Ferrari Bravo, D., Sassi, R., Rampinini, E., and Coutts, A.J. (2022) How do young soccer players train? A 5-year analysis of the training load and its variability in an elite youth academy. *Journal of Strength and Conditioning Research*. in press

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Connolly, D.R., Stolp, S., Gualtieri, A., Ferrari Bravo, D., Sassi, R., Rampinini, E., and Coutts, A.J. (2022) How do young soccer players train? A 5-year analysis of the differences in weekly micro-cycle training load across an elite youth academy. *International Journal of Sports Physiology and Performance*. in preparation.

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Connolly, D.R., Mercer, M., McLean, B., Rampinini, E., Coutts, A.J., (2022) Assessment of dose-response relationships between 1-week and 4-week cumulative training load and physical performance outcomes in elite youth soccer. *Science and Medicine in Football*. in preparation.

Conference proceedings

Connolly, D., Stolp, S., Gualtieri, A., Ferrari Bravo, D., Sassi, R., Rampinini, E., Coutts, A.J. (2022) How do young soccer players train? A 5-year analysis of elite academy players weekly training load and its distribution across a micro-cycle. *World Congress on Science and Soccer*. Coimbra, Portugal

Connolly, D., Stolp, S., Rampinini, E., Coutts, A.J., (2022) Training load variables in elite youth soccer: Is a data reduction approach consistent across different age groups? *World Congress on Science and Soccer*. Coimbra, Portugal

Abstract

Soccer is a team-based sport that requires prolonged high-intensity intermittent exercise and the execution of numerous different actions that elicit high levels of force. The stochastic nature of these phases requires players to stress a range of different physical capabilities. Developing these physical abilities concurrently (i.e., alongside technical, and tactical training) poses a significant challenge in managing players training loads, and therefore requires a systematic approach to training design and management. The widespread use of player monitoring tools and quantity of data provided by micro-technology requires a greater understanding which parameters should be examined and also the variation that can occur in these parameters through a competitive season. The objective of this thesis was to aid practitioners by conducting an in-depth analysis of real-world data and applied scenarios that occur in an elite level academy. A specific objective was to assess and provide insights into the differences (if any) between different age groups and contribute towards advancing current knowledge regarding "how they train" and the evolution of players physical capacities. This thesis contains 7 independent studies which aim to describe the training loads incurred by elite-level youth soccer players, identify the constructs that can help to prescribe training, remove data redundancy by identifying the variables that parsimoniously describe the training load performed, and finally, describe the association between select training load variables and physical outcomes in this specific population.

Study one was a systematic literature review that investigated the relationship between training load variables and the performance outcomes in youth soccer players. The main findings highlighted that a limited number of studies (n = 10) reported inconsistent relationships for both aerobic and neuromuscular capabilities. Whilst there was low to moderate risk of bias in previous studies, the present analysis showed these studies findings were imprecise, inconsistent, and indirect. The review highlighted the need for additional research examining the associations between select training load variables (over acute and chronic periods) based on well justified conceptual frameworks and consistent reporting methods.

The second study examined the levels of training load accrued accumulated during in-season training weeks in four age groups (i.e., U15, U16, U17, and U19) of an elite youth soccer academy. The results present a progression in players perceived training load levels from U15 to U17, with a subsequent reduction in load in the U19. This study also presented differences in the levels of training load performed between starters and non-starters and a limited degree of variability between training

weeks. Study three described how these training loads were distributed across a weekly microcycle in the different age groups of an elite youth soccer academy. Results showed that the match day was the most intense session of the training week across all age groups and the application of a different weekly training load distribution in the youngest and oldest age groups of the academy. Study four investigated which training metrics provided by wearable microtechnology during training and competition influenced the players sRPE. This study identified that total distance, very high-speed running, and a moderate heart rate threshold to be the major contributors to sRPE.

A practical problem for sports scientists assessing training load in soccer is handling the vast array of data being recorded from each session for each player. Therefore, studies five and six applied two different approaches to applying Principal Component Analysis (PCA) on a dataset consisting of 82 training load variables to identify components and/or variables that described the most variance in the training load. Study five used an unguided approach and study six used a guided approach. This process was also undertaken to ensure that the metrics included in the academy's training load monitoring program were not omitting a variable (or group of variables) that could aid training prescription, or alternatively including unnecessary variables in the training load analysis. The results of study five demonstrated that, when unguided variable input was used for the PCA, numerous variables are required to describe training load and that the PCA outputs were subtly different in each of the four different age groups. In addition, after data reduction (i.e., PCA), 7 components and 25 variables were retained in study five, and these results were deemed to have limited practical applications for interpreting training load in an applied setting. Therefore, in study six, a conceptual framework based on current literature and expert opinion was then developed and applied to guide training load variable selection in a follow-up PCA. The results of study six identified four components of load (i.e., the total volume of load, acceleration load, the quantity of high-speed running, and heart rate load), including both internal and external load, that should be considered in a load monitoring program. The variance described was relatively stable across the four components, despite differences in the weighting of different variables in some of the age groups.

The final study (study seven) assessed the dose-response relationship between select training load variables with fitness outcomes (i.e., aerobic fitness, high-intensity intermittent running capacity, and neuromuscular power) across three different age categories. The results demonstrate that age group and test period influence both physical outcomes and the quantity of load performed in that phase of the competitive season. We observed that changes in aerobic fitness was not related to the quantity of load accumulated over 1- or 4-week periods for any load variable. In contrast, both acute (1-week) and chronic (4-week) sRPE and very high-speed running training loads were shown to be associated with improvements in countermovement jump power values.

The collective findings in this thesis provide a new detailed description of the quantity and distribution of sRPE training load performed by elite youth soccer players, highlighting the importance of controlling training duration to manage training load and identify contextual factors that influence periodisation strategies. The present results also question the efficacy of applying PCA as a data reduction method to agnostically identify constructs of training loads for the purposes of player monitoring. The findings also highlight the complex nature of the dose-response relationship between training load variables and fitness outcomes. Additionally, the results of each individual study highlight subtle differences between age groups, their periodization strategy and trends in the evolution of players physical capacity. Key learnings for practitioners are provided through demonstrating an evidence-informed approach to player monitoring and show how the importance of various player monitoring data can be assessed through the research process. Collectively, the findings of this thesis support the application of a conceptual framework for the identification of suitable training load constructs and the metrics to be included in a training load monitoring system for elite youth soccer players. Indeed, it is recommended that practitioners and scientists embrace the uncertainty and individual differences that exists in the complex system of training youth footballers. These findings can be used to refine and enhance the approach to player monitoring in a world class youth academy, but with the acknowledgement the there is a complex relationship between training loads and outcomes in elite youth football. Further research is required to identify other methods that can provide practical insights to the monitoring process and facilitate players long-term development.

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List of Abbreviations

%	Percentage
30ASR	30% anaerobic speed reserve
ACC	Accelerations
AD	Acceleration distance
AIC	Akaike information criterion
ANOVA	Analysis of Variance
AU	Arbitrary units
CI	Confidence interval
CMJ	Countermovement Jump
CMJA	Countermovement Jump with arm swing
CMJD	Countermovement jump with single dominant leg
CMJnD	Countermovement jump with single non-dominant leg
CR	Category ratio
CV	Coefficient of variation
DEC	Decelerations
d	Cohen’s d effect size
df	Degrees of freedom
EPPP	Premier League’s Elite Player Performance Plan
ES	Effect size
FIFA	Internationale de Football Association
GPS	Global Positioning System
GTG	Generic training group
h	hour
HIT	High Intensity Intermittent running test
HR	Heart rate
HR85-90%	Time spent between 85% and 90% of heart rate max
HR90%	Time spent above 90% of heart rate max
HRmax	Heart rate max
HSD	High-speed distance
HRE	Heart rate exertion
HSR	High-speed running
IN1	Beginning of the competitive season
IN2	Halfway through the competitive season
IN3	Before the final stage and play-offs
ISRT	Intermittent shuttle running test
iTRIMP	Individualized training impulse
kg	Kilogram
km	Kilometre

KMO	Kaiser-Meyer-Olkin
Lac	Blood lactate accumulation
LT	Lactate threshold
LTHR	Heart rate at lactate threshold
LTAD	Long-Term Athlete Development
m	Metre
m>MAS	Distance covered above maximum aerobic speed
MAS	Maximal aerobic speed
MD	Matchday
MD-x	x-days before the next match
min	Minute
mmol/L	millimole per litre
MSS	Maximal sprint speed
n	Number / Sample size
NRCT	Non-randomized control trial
OBLA	Onset of blood lactate accumulation (4.0 mmol/L)
OBLAHR	Heart rate at onset of blood lactate accumulation
OSF	Open Science Framework
p	P-value
PC	Principal component
PCA	Principal component analysis
PRE	Preseason training
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews
PVT-CAR	Peak velocity derived from the Carminatti test
r	correlation coefficient
ROBINS-I	Risk of Bias in Non-randomized studies of Interventions
RPE	Rating of perceived exertion
RSA	Repeated sprint ability
SD	Standard deviation
SE	Standard error
SJ	Squat Jump
SPR	Sprint
SPSS	Statistical Package for the Social Sciences
sRPE	Session Rating of perceived exertion
sRPEmus	Muscular rating of perceived exertion
sRPEres	Respiratory rating of perceived exertion
STG	Specific training group
SWC	Smallest worthwhile change
t>MAS	Time spent above maximum aerobic speed
t>30ASR	Time spent above 30% anaerobic speed reserve

T-CAR	Carminatti Test
THIR	Total high-intensity-running distance
TD	Total distance
TL	Training Load
TLd	Training duration
TRIMP	Training Impulse
UEFA	Union of European Football Associations
UMTT	Université de Montreal track test
v	Velocity
V3	Running velocity with a blood lactate accumulation of 3 mmol/L
VHSD	Very high-speed distance
VHSR	Very high-speed running
VO_2max	Maximal Oxygen Consumption
VHSR	Very high-speed running
W	Watts
YYIRT1	Yo-yo intermittent recovery level 1

CHAPTER ONE

Introduction

1.1 Background

Soccer, more formally known as association football, with an estimated 250 million players active in over 200 countries, and billions of global fans, is considered the world's most popular sport [1, 2]. The Federation Internationale de Football Association (FIFA), founded in 1904, serves as the international governing body of soccer and is composed of both men's and women's clubs, comprising 205 member associations with over 300,000 clubs globally. The two most prestigious competitions in men’s football are the Union of European Football Associations **(**UEFA) Champions League and the FIFA World Cup, which attract an extensive global television audience and enormous financial returns for the participating clubs. The final of each of these tournaments is most often the most-watched annual sporting event in the world [3]. Due to its global popularity and opportunity for financial rewards for players and successful teams, clubs make a considerable investment into developing talented players. The most common approach is through youth academies - which are present in most large professional soccer clubs – where talented players are often identified from a young age and then enter a talent development program, which is aimed to develop them for future success as adult players.

One of the primary goals for soccer talent development programs is to develop young soccer players so they can cope with the demands of elite senior soccer match-play [4, 5]. Indeed, elite youth soccer academies play a crucial role in the talent development processes [4, 6], in which they seek to maximize the long-term physical development of their athletes through appropriate periodization and the implementation of Long-Term Athlete Development (LTAD) strategies [7]. A critical aspect of athletic development is the periodisation of the training load. The training load is the primary stimulus for the adaptive responses to build the physical and physiological capacities required to perform in high-level soccer.

To compete at the elite level, soccer players are required to undertake prolonged high-intensity intermittent exercise which requires the development of different physical capacities [8]. Professional soccer players travel a total distance of 10–12 km at an intensity between 80-90% of the players maximal heart rate (HR) during matches [9]. This activity is stochastic with players changing activity every 5 seconds and performing ~200 intense actions during a match [10]. Players must also perform numerous explosive and intense actions requiring a high level of force production, such as decelerations, kicking, dribbling, and tackling during a competitive match [8]. However, the quantity and intensity of work performed by the different players will be also shown to be dependent on position-specific tactical requirements [11, 12]. The combination of all these physical attributes and the increasing intensity at which the game is played [13] provides a challenge for the coaching and performance staff in preparing players for competition. Increasingly comprehensive and accurate quantification of loads has contributed to numerous studies documenting the evolution of youth soccer players match running performance [14]. For example, age-related increases in match running performance when utilizing fixed speed thresholds [14] with high-speed running distances of Under 16 and Under 18 age groups resulting similar to elite level adult players [15]. This aspect is of particular interest to elite-level academies, where the increased requirements of physical match demands and high-intensity efforts across the different age groups [16, 17] require adapting the training plan and achieving a progression in players physical adaptations [16]. Informing conditioning programs on the basis of the match demands of different age groups and providing age-group specific reference values can help to fine-tune training prescription [14].

An essential characteristic of the training process lies in the accurate quantification of the training load performed by the athletes. Systematic monitoring of players individual training practices is now an integrated part of the daily practice in the majority of elite-level football clubs and their youth academies [18]. A survey conducted on football academy staff from the United Kingdom, including elite and sub-elite level teams, identified training load monitoring to be important for numerous different factors, including injury prevention, prescription and individualization of training, coach feedback and overall player development [19]. Indeed, the basis for developing load monitoring systems is to better understand and control the training loads that the players are exposed to. This is achieved through measuring and manipulating training frequency, intensity, duration, mode, and distribution [20]. The information obtained through this approach can also be used to inform the prescription of future training to better meet the targeted outcomes. Indeed, a comprehensive monitoring program must assess the training load sustained during technical-tactical training sessions, gym-based sessions, as well as matches to assess the total training load being performed by each player. One of the real challenges that practitioners face in achieving this, however, relates to the large quantity of data (and different metrics) that can be used to assess the load from these diverse training activities. Indeed, the diverse nature of training activities in soccer (i.e., technical and tactical drills, small-sided games, training matches, etc. [21]) makes it challenging for practitioners to identify indicators of training loads that best represent the training stimulus.

A common approach to describing the training load in soccer describes two distinct elements: the internal and external load [22]. External load is defined as the quantity and intensity of work completed by the athlete, measured independently of the player's characteristics or fitness levels. The external load imposed on the soccer players during sport-specific training typically relates to the measures of total distance covered, distances covered above different speed thresholds, as well as the number and intensity of accelerations (ACC) and decelerations (DEC) performed. Recent advances in wearable technologies (e.g., global positioning systems (GPS) and accelerometers) allow practitioners to gain detailed insight into the volume and intensity of training stimulus applied, providing an increasingly comprehensive and accurate quantification of each players training load [23, 24]. The internal load relates to the psycho-physiological stress induced to perform the external work. This can be assessed utilizing biological markers such as HR, blood lactate, and oxygen consumption, as well as via subjective measures of load. The most widely utilized subjective measure is the session rating of perceived exertion [25, 26]; a simple method that can be applied at any level and across all training activities.

Assessing a combination of both internal and external load measures appears to be the most comprehensive approach for assessing the training process [27]. However, the absence of a gold standard measure of training load in youth soccer and the availability of a large number of load monitoring measures and metrics has resulted in a large number of different variables being considered in this process [26]. The selection of these metrics, and the methods by which they are obtained, are dependent upon the context of the sport and require careful consideration by practitioners. In practice, it is common for the selection of load variables utilized in the daily monitoring program and the weighting of the importance of each internal and external load marker to be based on the training philosophy applied within the specific club (i.e., context). However, to achieve the best outcomes, the training process should be quantified utilizing appropriate methods. Indeed, valid, and reliable measures of training load that are context appropriate are essential components of athlete monitoring systems. This approach is a significant part of the daily work of sports scientists working in elite youth soccer academies.

Wearable microtechnology, including the use of GPS devices, accelerometers and inertial sensors [28], has significantly impacted athlete development and player care programs in elite-level soccer clubs and their youth academies. The information provided by these devices can provide insights into the quantity and nature of training being performed by each player [23, 24]. Indeed, the common use of these data is to describe the loads experienced by players in training and matches. Including differences between playing standards, between playing positions differences, and other constraints relating to the schedule, travel or environmental factors [14]. Typically, these studies are conducted on single club cohorts with a reduced number of players and short timeframes, addressing different questions and issues relating to characterising and comparing outcomes or investigating correlations within the data recorded [14]. Whilst there are many reports of the match activity demands of elite youth soccer players, there are relatively few descriptions of the training demands of these players [15, 29-31]. However, these studies are limited in their sample and the findings are difficult to generalise broadly.

One possible reason for the relative lack of information about the training load characteristics of highly trained youth soccer players in elite level teams academies [32] is the difficulty in handling the amount of information that is now collected and subsequent dissemination of this information. Commercially available GPS units provide large amounts of data across a great number of different velocity and duration-derived metrics, often reported in different intensity thresholds [2, 7]. Furthermore, these recent advances in wearable technology are to be considered alongside internal load measures recording psycho-physiological stress induced in order to perform the load [33]. However, the large amount of data provided by these devices has become an issue, as a large quantity of the data may be redundant and confound the athlete monitoring process. Indeed, the training load variables selected must provide meaningful information on different constructs of load that relate to performance outcomes of training adaptations [3-5]. From a practical perspective, practitioners require that these large data sets be reduced so that a parsimonious number of variables can be used to inform the training prescription process. At present, there have been few studies that have demonstrated feasible methods to reduce these data in a manner that can be applied in practice.

Training Loads in Elite Youth Soccer

The increased availability of various load-measurement tools and physical capacity assessments has led to a greater understanding of the match and training demands in youth soccer. Indeed it has been shown that similar to adult players, youth soccer match play is also physically demanding, requiring both aerobic and anaerobic capabilities and high levels of strength and power [8]. Developing these physical abilities concurrently poses a significant challenge and requires a systematic approach to planning and delivering training [34]. Furthering our knowledge in this area is essential for assisting coaches in the design and management of training programs that allow players to better cope with the increasing match demands across the different age groups [16]. The nature of soccer training is often based upon the aim of replicating the movement demands and technical requirements of match play, as well as developing player's physiological capabilities. This can be achieved utilizing both generic running drills and sport-specific drills (e.g. small-sided games) [35]. Despite the increasing availability of wearable technologies to quantify players training load during the sessions, there are relatively few reports on the specific training demands of elite-level youth football in academies. To date, elite youth soccer player in-season weekly training load and its distribution across a weekly microcycle has been assessed from low sample sizes and short periods of a specific season [15, 36, 37]). Practitioners working in youth soccer require further insights to implement an appropriate physical conditioning progression, preparing the players for specific high-intensity training and match demands.

To date, the quantity and distribution of work performed by youth players have been described in terms of the training loads completed during both weekly micro-cycles and longer periods of training (i.e., competitive season). Small variations have been reported during in-season training blocks (4-8 weeks) suggesting that the training performed is similar throughout the competitive season [38-41]. However, substantial differences in training load have been reported within weekly microcycles, where there appears to be a progressive "loading phase" before a marked reduction in load (tapering phase) preceding the next competitive match [31, 40, 42]. This trend has been observed to be greater in under 18 players compared to younger age groups (U14 and U16, respectively) [36]. The content of the training sessions and differences between player developmental ages may also account for differences in weekly loading strategies [37]. To the best of our knowledge, no studies have described the training demands of the players progression across the different age groups of an elite-level academy (i.e., belonging to a world class soccer club). Understanding the age-related differences in levels of training load is essential for developing a strategy for the continued growth of youth soccer players' physical capabilities; a factor that is increasingly important in elite-level football academies.

This information is key to facilitating the tailoring of training sessions that train both players physical and technical requirements. However, to date little is known relating to the type of training and quantity of load to be performed to achieve improvements in youth players physical outputs. Gaining a better understanding of the variables and quantity of work to be performed can facilitate the prescription of an integrated training program with the coaching staff.

Physical Assessments

The physiological capacities and abilities required for elite soccer performance include the development of players aerobic capacity, high-intensity intermittent running ability, repeated-sprint ability, maximal muscle strength, and (or) explosive power [43]. The requirement to develop these capacities concurrently poses a significant challenge for sports science practitioners who are responsible for training prescription and physical loading. Specifically, the training should be prescribed in a manner that develops each of these capacities, whilst also allowing time in the training program for optimal development of technical and tactical attributes. Physical fitness assessments are commonly prescribed to quantify each individual athletes physical capabilities, gain a further insight into strengths / weaknesses, and importantly, players response to the training stimulus that they have been exposed to [44]. Submaximal fitness tests, that require a non-exhaustive effort, are often employed in team sports as they are easier to program within teams' schedule, retain high levels of validity and repeatability and are not influenced by players motivation to perform maximal efforts [44, 45]. The evaluation of players physiological state helps to provide individualized information that can feedback into the decision making process and inform training prescription [45].

Performing periodical physiological assessments can be applied to track the longitudinal adaptations in physical capacity, providing a comprehensive understanding of players' physical development. Monitoring seasonal variations across different age groups can be used to provide insights into the long-term development of players' physical abilities and talent identification [46]. Developing young players' physical qualities can help them to achieve their full potential, facilitating increased performances while also actively contributing toward injury prevention [47]. Indeed, many high-level soccer academies invest significant time and resources towards monitoring and developing these abilities.

The complex nature of physiological and biomechanical load adaptions in team sports [48] has contributed to a wide range of physical assessments being adopted to evaluate changes in youth players' physical condition. Most commonly, these evaluations have been applied to assess if specific training programs have improved specific physical qualities related to soccer performance (e.g. aerobic qualities, sprints, countermovement jumps, etc.) [49]. Different training protocols, for example, high-intensity interval training and small-sided games are equally effective in improving junior soccer players physical fitness [49-51]. Other studies have shown that small changes in increasing training volume (i.e., ~1 h/week) can induce improvements in players intermittent running capacity [52] in young elite soccer players. Several other studies have examined the relationship between physical test performance and match activities, highlighting an association between young soccer players endurance capabilities and the quantity of work performed during matches [53-57]. Collectively, these studies have provided a conceptual link between the training load and physical performance outcomes. Indeed, a limited number of studies have specifically aimed to investigate the existence of a "dose-response relationship" between the training stimuli performed by the athletes and changes in their physical fitness levels [58-60]. However, despite this understanding, and the widespread use of load monitoring and regular physical assessments in youth soccer, the relationships between these variables are under investigated. [61] and/or a conceptual frameworks to help synthesize relationships and guide the selection of variables [62] can greatly facilitate the identification of training load variables to retain within a player monitor system. Accordingly, further evidence is required to determine which load variables (e.g., internal, or external load variables) or a combination of variables, can contribute to improvements in youth football players fitness levels and physical capacities.

1.2 Research Questions and Significance

The increased availability of wearable technology and athlete monitoring tools have now made it relatively simple to quantify the training and competition demands of sports such as soccer. Such information is critical to understanding the sport-specific athletic requirements which can optimise athlete training programs and development. Despite the pervasiveness of athlete monitoring and the resultant availability of data, there have been relatively few detailed reports of the training loads experienced by elite youth soccer players. Moreover, there is also a poor understanding of the dose-response relationships between training load measures and important outcome variables including players physical capacities. A greater understanding of these issues is required as it may be used to inform practices of sports scientists in selecting appropriate load monitoring variables and providing age-appropriate advice for training prescription in elite youth soccer players.

To address this issue a series of related studies were conducted, with specific research questions under three general themes:

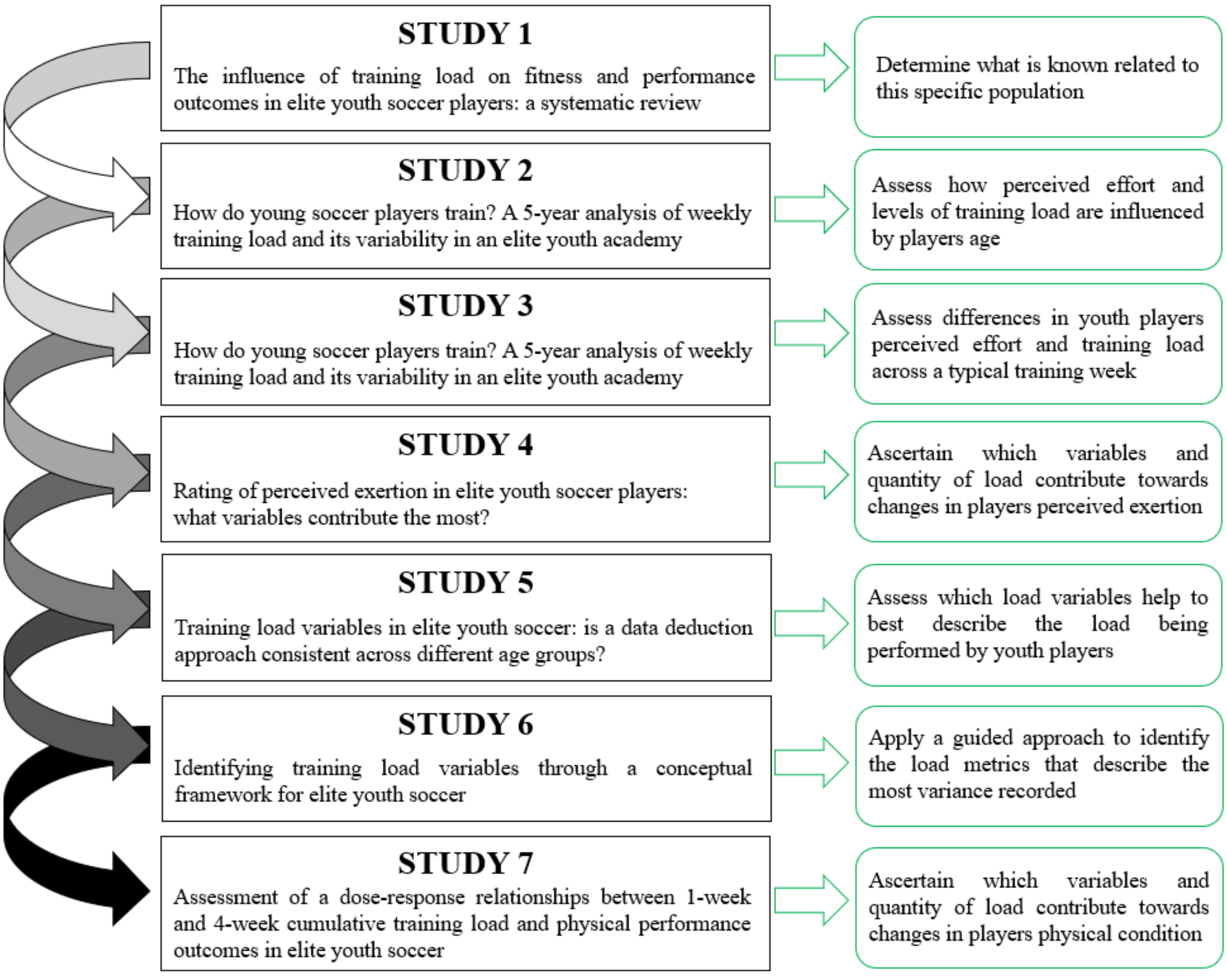
- *Description* – to quantify the perceived intensity and duration of the training and competition performed by elite youth football to describe the levels of load, its distribution, and progression across the different age groups of an entire academy.

- *Reduction* – to identify the load variables that contribute the most towards elite youth players perception of effort and determine which metrics and/or constructs of load describe the greatest amount of variance being recorded by the player monitoring program.
- *Association* – to establish the strength of associations between meaningful variables with outcome measures relating to elite youth players physical capabilities over short and longer periods of training.

Assessing the relationship between training activities, the physical load incurred, and players fitness levels can provide more in-depth knowledge directly related to training load control. Gaining further insights relating to a dose-response relationship can facilitate the optimization of training prescription in youth football. Developing a better understanding of the workloads being performed can facilitate both an evidence-based approach and the decision-making process.

1.3 Research Overview

The Ph.D. thesis will encompass a series of studies with the collective aims of describing the quantity and variation of load that players are exposed to, assessing which variables influence players perception of effort, and reducing the number of variables included in a player monitoring program before evaluating the influence of these load metrics on youth soccer players physical performance. These projects aim to set out a practical, evidence-based approach for the monitoring and prescription of training load in youth soccer academies (Figure 1.1).



STUDY 1

The influence of training load on fitness and performance outcomes in elite youth soccer players: a systematic review

Determine what is known related to this specific population

STUDY 2

How do young soccer players train? A 5-year analysis of weekly training load and its variability in an elite youth academy

Assess how perceived effort and levels of training load are influenced by players age

STUDY 3

How do young soccer players train? A 5-year analysis of weekly training load and its variability in an elite youth academy

Assess differences in youth players perceived effort and training load across a typical training week

STUDY 4

Rating of perceived exertion in elite youth soccer players: what variables contribute the most?

Ascertain which variables and quantity of load contribute towards changes in players perceived exertion

STUDY 5

Training load variables in elite youth soccer: is a data deduction approach consistent across different age groups?

Assess which load variables help to best describe the load being performed by youth players

STUDY 6

Identifying training load variables through a conceptual framework for elite youth soccer

Apply a guided approach to identify the load metrics that describe the most variance recorded

STUDY 7

Assessment of a dose-response relationships between 1-week and 4-week cumulative training load and physical performance outcomes in elite youth soccer

Ascertain which variables and quantity of load contribute towards changes in players physical condition

Figure 1.1. Overview of the aims of each of the original studies included in the Ph.D. Thesis.

CHAPTER TWO

Literature Review

Study One: The influence of training load on fitness and performance outcomes in elite youth soccer players: a systematic review

Chapter preface

This systematic review investigated the current literature to determine was known about regarding a dose-response relationship between training and performance outcomes in youth soccer. This was achieved by establishing a series of keywords relating to the specific research area and population, before systematically reviewing all articles identified. This systematic review helped to identify the common variables and testing protocols utilized in the available literature and identify gaps in knowledge relating to the association between training and physiological outcomes. In general, it was shown that there is limited information available with only 10 studies meeting inclusion criteria. Whilst the studies were found to have low to moderate risk of bias, there reported relationships between training load variables and fitness outcome were imprecise, inconsistent, and indirect. This study had several important outcomes, identifying varying relationships for different load variables, across different time frames, with both endurance and neuromuscular aspects.

2.1 Introduction

Soccer is a team-based sport that involves prolonged high-intensity intermittent exercise [63] and necessitates that players utilize a wide range of different physical abilities. The stochastic nature of the game requires players to change activity approximately every 5 seconds [10] and perform numerous explosive and intense actions that elicit high levels of force production (e.g. decelerations, kicking, dribbling, and tackling) [8]. It has been documented that players complete over 200 actions at high-intensity during a match [10], with the quantity of high-intensity running and number of sprints reported having increased significantly in recent years (+30% between 2006-07 and 2012-13) [11]. Position-specific tactical requirements have also been reported to influence the quantity and intensity of physical work performed by players [11, 12]. In recent years a growing body of evidence describing the physical match performances in youth soccer players has emerged, highlighting increasing demands in training and matches in older age groups [14, 15, 64] and a progression in high-speed running distance during matches with age [65].

The myriad of factors that contribute to soccer performance poses a significant challenge for the development of youth soccer players' physical abilities. Long-term athlete development is a multi-factorial process and a key objective for elite football academies aiming to best prepare youth athletes for the demands of elite-level soccer [6, 66]. Aerobic capacity, high-intensity intermittent running ability, repeated-sprint ability, maximal muscle strength, and explosive power all contribute to elite-level soccer performance [63], and players ability to cope with the training and match demands. The development of these diverse physical aspects is essential to compete at a professional level, where aerobic performance [67], intermittent endurance running, and repeated-sprint ability [68-70] have all been found to discriminate between players of different competitive levels [71-74].

Desired training responses (i.e., the development of physical abilities and capacities) can be moderated by the quantity, quality, and organization of work prescribed [75]. Indeed, manipulating the training load, via changes in training frequency, duration, mode, intensity, and distribution of training can each influence the training outcomes [20]. The periodization of these aspects within a specific period or across the entire competitive season and how athletes physically respond to the training stimulus [76]. Each of these factors can directly influence the association between training and changes in physical fitness levels, also known as a "dose-response relationship". The increasing availability of load-measurement tools (i.e., wearable technology) has allowed for the broadening of load metrics assessed in youth soccer players during training and matches [23, 24]. This systematic monitoring of training load is now an integrated part of daily practice in the majority of elite-level football clubs and their youth academies [18].

The process of evaluating training loads and providing feedback for the training prescription process is deemed essential to optimising the training process [20, 77]. The lack of agreement regarding the best measures for the quantification of athletes' responses to training results has led to a large number of different variables being considered in this process [26]. Although reporting a combination of both internal and external load is suggested to be the most thorough approach for assessing training and its periodization [35], it is uncommon for both these constructs of load to be reported concurrently. Where the external load imposed on players during training relates to the measures of total distance covered, distances covered above different speed thresholds, as well as the number and intensity of accelerations and decelerations performed [23, 24]. While the internal load of training and matches relates to the psycho-physiological stress induced by performing the external work. This can be assessed utilizing objective (e.g., biological markers such as heart rate, blood lactate, oxygen consumption) and subjective measures of load. The most widely utilized subjective measure is the session rating of perceived exertion (sRPE) [26, 78, 79]; a simple, inexpensive, and non-invasive method that can be applied at any level and across all training activities.

A growing body of research has aimed to describe the dose-response relationship between the training loads that team sport athletes are exposed to, and the physical and physiological adaptations that ensue [80]. In soccer, the few studies that have been conducted have reported that training loads performed at high intensity are associated with positive changes in aerobic fitness levels (e.g., a positive relationship has been reported between time spent above high-intensity heart rate thresholds in pre-season and endurance performance) [81-83]. The relationships with neuromuscular assessments are unclear as both positive and negative results have been reported [58]. However, this information is limited as comparability between the different methods applied across studies (both in terms of periods assessed and test selection) is difficult, and small sample sizes indicate that findings should be interpreted with caution.

One of the key objectives of elite-level youth soccer academies is the development of talent-identified players so that they can achieve professional status [84]. This requires the clubs to adopt a multidisciplinary approach that includes the systematic measurement of players physical capacities and the assessment of their longitudinal physical development [85]. Previous studies have identified youth players endurance ability and speed to be potential predictors of progression from youth to senior football in an elite Scottish club [86], with the importance of these physical indicators potentially changing across the different age groups. Understanding the influence that players training loads can have on the physical adaptations induced in these specific age groups can contribute to improvements in physical fitness while reducing the likelihood of negative outcomes like poor physical responses, injury, or illness [20, 77].

Gaining a more in-depth understanding of the relationship between the training load performed during training and competition, and its impact on players' fitness or physical capacity can provide practitioners with important insights for the training prescription process. This approach is of significant interest in elite youth soccer because it can directly aid practitioners to inform decisions related to training plans aimed at improving players physical capacity. However, to date, no studies have systematically assessed the evidence relating to a dose-response relationship in this specific population or reported whether findings are analogous to those of senior-level players. The development of an evidence-based assessment of the training dose and responses can contribute towards a greater individualization of the training prescription process within youth academies and across the different age groups. Therefore, this review aims to assess the evidence available in current literature relating to the association between the training load and improvements in youth soccer players physical performance.

2.2 Methods

The screening process was conducted following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [87]. Following the guidelines, our systematic review was also registered with the Open Science Framework (OSF) on the 7th of June 2019 and was last updated on the 21st of May 2021.

Literature search strategy

A pilot search was initially conducted (screening of titles, abstracts, keywords, and full texts of articles related to the specific topic) to identify keywords that encompass all relevant literature. The original research articles considered in this review were identified through a systematic search of three electronic databases: PubMed, Web of Science, and SPORTDiscus. The selection of keywords and grouping of the variables (connected with OR) utilized in the search strategy is presented in table 2.1. The search strategy applied each variable independently before a combination of all three groups (population, load, and performance) using AND in the final word search. The search was conducted on the 11th of April 2019 and was restricted to English peer-reviewed articles published before April 2019.

Table 2.1. Search strategy utilized to identify relevant research articles.

Variable	Search terms
Population	(‘football’ OR ‘soccer’) AND (‘youth’ OR ‘young’ OR ‘junior’ OR ‘adolescent’)
Load	(‘training’ OR ‘load’ OR ‘practice’ OR ‘match’ OR ‘game’ OR competition OR ‘volume’ OR ‘duration’ OR ‘GPS’ OR ‘PlayerLoad’ OR ‘rating of perceived exertion’ OR ‘accelerometer’)
Performance	(‘physical’ OR ‘fitness’ OR ‘performance’ OR ‘physiological’ OR ‘intensity’ OR ‘ability’ OR ‘aerobic’ OR ‘anaerobic’ OR ‘workload’ OR ‘exposure’ OR ‘outcomes’ OR ‘internal’ OR ‘external’ OR ‘intermittent’ OR ‘endurance’ OR ‘speed’ OR ‘agility’ OR ‘repeated-sprint’ OR ‘strength’ OR ‘muscular’ OR ‘neuromuscular’)
Final Search	Combination of three groups: ‘Population’ AND ‘Load’ AND ‘Performance’

Selection Criteria

The title and abstract of each study were retrieved from the respective electronic bibliographic databases using reference management software (EndNoteTM X9.2, Thomson Reuters, New York, NY, USA). The search results were subsequently imported into a web-based software, Covidence (Melbourne, Australia, 2019), to facilitate the screening process. Following the exclusion of all duplicates, the title and abstract of every article were screened independently by two authors (Darragh Connolly (DC), Aaron James Coutts (AJC)). Articles considered for inclusion in the review were required to investigate a dose-response relationship between training load (internal and external, following Impellizzeri’s classification [22]) and fitness and performance measures, specifically in youth soccer. The inclusion criteria specifically targeted youth academy players between the ages of 14 and 21 y. Articles were excluded if: 1) the participants were not male 2) the participants mean age was younger than 14 y of age; 3) the participants mean age was older than 21y of age; 3) the articles did not report any measures of load, in their interventions; 5) the load data reported was not complete across the monitoring period 6) participants were recreational level athletes 7) the articles were reviews, case studies or abstracts from conference proceedings. A full-text review was subsequently conducted, using the same criteria, on a total of 78 studies. Any disagreements relating to the inclusion-exclusion status of the studies were resolved through further discussion (n = 10). The selection process identified 10 original research articles that met the inclusion criteria. The full details relating to the screening process are presented in Figure 2.1. At this stage, the reference lists of the articles selected following full-text review and relevant review articles were cross-checked manually for potential non-identified articles to incorporate. No additional relevant articles were identified via this process. The final list of articles retained was then double-checked by the authors conducting the screening process prior to proceeding.

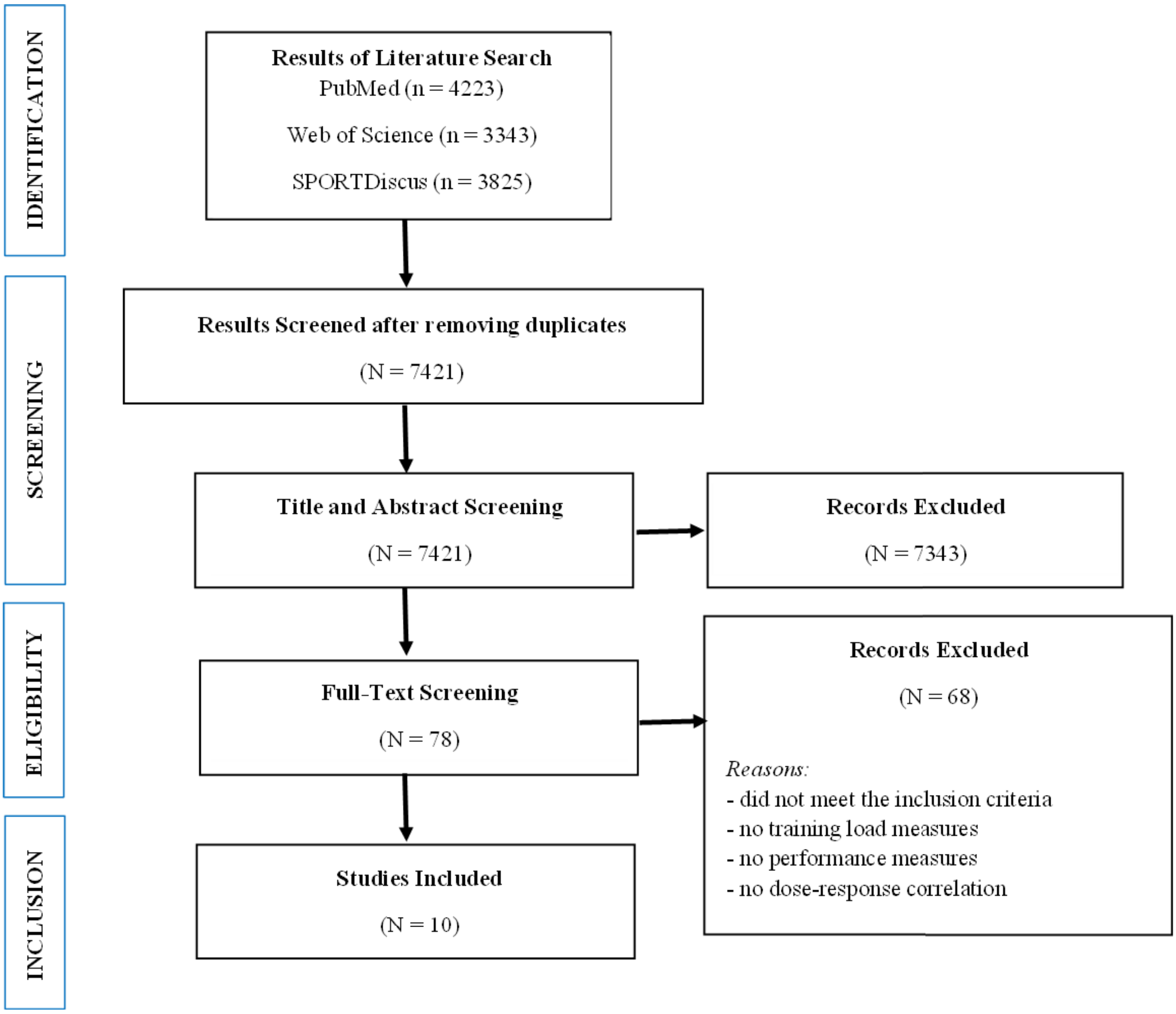


Figure 2.1. Flow chart for inclusion and exclusion criteria.

Assessment of Methodological Quality

Risk of bias assessment was performed on the selected articles to appraise the methodological quality of the interventions. The Cochrane Collaboration's Tool for assessing the Risk of Bias in Non-randomized studies of Interventions (ROBINS-I) [88] was selected due to the nature of the studies included. The ROBINS-I tool is recommend for assessing the risk of bias in non-randomized studies of interventions, it is structured to into a fixed set of domains that include signalling questions that inform the overall risk of bias judgment. Based on the answers to the questions, evaluating the methodological approach and content of the individual articles, overall risk of bias can be low, moderate, serious or critical. Two review authors (DC and AJC) independently assessed the single studies, any conflicts in bias assessment were further discussed, and a third party was consulted (Ermanno Rampinini (ER)) if consensus could not be reached. The inter assessor reliability of the researchers assessing the articles was 95%.

Data extraction and analysis

Upon completion of this phase, data was extracted from the 10 articles by the lead author (DC). The sample size and participants' characteristics, including the level of player, are presented in Table 2.2. The training period assessed, and the range of training load and performance measures evaluated in each study are presented in Table 2.3. All the significant results relating to a dose-response relationship reported in each article (e.g., statistical values highlighting a correlation) are summarized in Table 2.4. The diversity in the range of training load measures and outcome measures reported does not allow for the pooling of data and implementation of a meta-analysis, however, we have reported correlations and effect sizes from individual studies to interpret the strength of the relationships reported.

2.3 Results

The screening process identified ten articles that met all the inclusion criteria. A methodological quality appraisal of the 10 studies was conducted using the ROBINS-I tool. The overall risk of bias was found to be low to moderate across all 10 studies (Table 2.2). The assessment of methodological quality did not result in any of the articles being excluded from the analysis. If none of the answers to the signalling questions indicate the presence of a potential problem, then risk of bias for the domain can be judged to be "LOW" [88].

Table 2.2. Summary of Risk of Bias Assessment (ROBINS-I).

Study	**Study Design**	**Bias due to confounding**	**Bias in selection of participants**	**Bias in classification of interventions**	**Bias due to deviations from intended interventions**	**Bias due to missing data**	**Bias in measurement of outcomes**	**Bias in selection of the reported result**	**Overall Risk of Bias**
	1	2	3	4	5	6	7	8	
Akubat et al. (2012)	NRCT	LOW	LOW	NI	MODERATE	MODERATE	LOW	MODERATE	MODERATE
Brink et al. (2010)	NRCT	LOW	LOW	NI	LOW	LOW	LOW	LOW	LOW
Cetolin et al. (2018)	NRCT	LOW	LOW	NI	LOW	LOW	LOW	LOW	LOW
Fitzpatrick et al. (2018)	NRCT	LOW	LOW	NI	LOW	LOW	LOW	MODERATE	LOW
Gil-Rey et al. (2015)	NRCT	MODERATE	LOW	NI	LOW	LOW	LOW	MODERATE	LOW
Los Arcos et al. (2015)	NRCT	LOW	LOW	NI	LOW	LOW	LOW	MODERATE	LOW
Los Arcos et al. (2017)	NRCT	LOW	LOW	NI	LOW	LOW	LOW	LOW	LOW
Malone et al. (2015)	NRCT	LOW	LOW	NI	LOW	LOW	LOW	LOW	LOW
Sams et al. (2018)	NRCT	LOW	LOW	NI	LOW	LOW	LOW	LOW	LOW
Thorpe et al. (2015)	NRCT	LOW	LOW	NI	LOW	LOW	LOW	LOW	LOW

NRCT = non-randomized control trial

The details related to the participant characteristics are presented in Table 2.3. The youth players assessed in the studies were of a high playing standard (defined as professional, elite, or collegiate level), ranging from Under 15 to Under 21 age groups. The sample sizes utilized in the studies ranged from 9 to 18 per age group. The studies included different periods of the competitive season; pre-season (n = 1), in-season (n = 7) or a combination of both periods (n = 2) (Table 2.4). The duration of interventions varied from 1 to 32 weeks. The articles have described the training load accrued by the players using a range of different measures, evaluating training volume (min; n = 5), measures of internal load (n = 9), or both internal and external load measures (n = 2). Physical performance outcomes were evaluated by a range of different evaluations aimed at assessing endurance qualities (n = 9) and neuromuscular qualities (n = 8). The studies also implemented the testing protocols at different stages of their respective interventions (mainly PRE and POST), as well as at differing stages of the competitive season. The dose-response relationships observed across the 10 studies are summarized in Table 5 and elaborated upon below.

Table 2.3. Summary of the participant characteristics reporting the sample size, age, and anthropometric data of the athletes assessed in the studies included.

Study	Level of Play	Sample size (n)	Age (years)	Height (cm)	Weight (kg)
Akubat et al. (2012)	Professional junior	9	17 ± 1	181 ± 5	72.9 ± 6.7
Brink et al. (2010)	Young elite	18	17.0 ± 0.5	180.4 ± 7.3	72.4 ± 7.8
Cetolin et al. (2018)	Professional youth	30 (U15 n = 18, U19 n = 12)	U15: 14.7 ± 0.5 U19: 18.9 ± 0.9	U15: 169.1 ± 7.8 U19: 175.1 ± 7.4	U15: 59.1 ± 7.0 U19: 67.8 ± 7.5
Fitzpatrick et al. (2018)	Professional junior	14	17.1 ± 0.5	178 ± 4.6	70.9 ± 5.8
Gil-Rey et al. (2015)	Elite and non-elite Junior	28 (Elite n =14, Non-elite n = 14)	Elite: 17.6 ± 0.6 Non-elite:17.5 ± 0.5	Elite: 179.7 ± 5.6 Non-elite: 178.1 ± 5.6	Elite: 70.3 ± 4.4 Non-elite: 71.1 ± 6.5
Los Arcos et al. (2015)	Professional junior	14	20.6 ± 1.7	179 ± 6	73.5 ± 7.0
Los Arcos et al. (2017)	Young professional	14	20.6 ± 1.5	180 ± 5	73.6 ± 7.4
Malone et al. (2015)	Professional youth	9	16.4 ± 0.5	180 ± 6	71 ± 9
Sams et al. (2018)	Collegiate	18	20 ± 1	179 ± 6	75.6 ± 6.6
Thorpe et al. (2015)	Elite	10	19.1 ± 0.6	184 ± 7	75.4 ± 7.6

Data are presented as mean ± standard deviation (SD). GTG Generic training group, STG Specific training group.

Associations between Training Load and Endurance qualities

The relationship between training load measures and players endurance capacity was examined in 7 studies. Training and match volume were shown to have a large positive association with changes in aerobic fitness levels ($r = 0.71$) [89]. Greater duration of training the week before testing was found to have a positive effect on submaximal running performance [90]. This was confirmed over a longer period (32 weeks), where greater training and match volume was observed to have a large negative association with aerobic fitness parameters (i.e. greater volume contributes towards a greater reduction in lactate accumulation; $r > -0.57$ at 12 km/h, 13 km/h and the speed at which 3 millimole per litre (mmol/L) of lactate is recorded) [91]. However, a 9-week period including 5 weeks of pre-season only found a small non-significant association between training volume and continuous running capacity ($r = -0.21 – -0.37$) [92].

Inconsistent findings were reported for training load measures calculated using the sRPE method. No relationship was found between sRPE load and changes in submaximal performance test results [90, 93]. However, accumulated respiratory and muscular training load measures have been recorded to have a positive correlation with changes in players aerobic fitness levels, increasing time to exhaustion [89] and reducing the accumulation of blood lactate at fixed running speeds [91, 92]. No significant relationships were found between total training load (sRPE) and changes in intermittent running ability [94], with higher levels of total training load appearing to negatively influence mean sprint times in repeated sprint ability (RSA) tests [94].

Different internal and external training load metrics showed differing and inconsistent relationships with endurance performance outcomes. Changes in aerobic fitness levels were strongly related to individualized thresholds of internal load (Mean weekly individualized training impulse (iTRIMP); $r = 0.67$), as opposed to absolute thresholds of HR measures ($r < 0.3$ for the velocity at lactate threshold) [93]. In addition, the time and distance covered above maximal aerobic speed (MAS; $r= 0.77$ and $r = 0.50$, respectively) [95] and time spent above 30% anaerobic speed reserve (30ASR; $r = 0.62$) [95] were both shown to strongly relate to changes in aerobic fitness levels. However, unclear relationships were found between all other mean weekly arbitrary or individualised training load measures and changes in aerobic capacity (e.g. total distance or ACC distance) [95].

Associations between Training Load and Neuromuscular qualities

The relationship between various training load measures and player's neuromuscular qualities were examined in 7 studies. No significant correlations were found between change in jump height and any of the training load variables accumulated during a single training session (internal or external) [96]. However, fluctuations in total high-intensity running (>14.4 km/h) appear to influence countermovement jump (CMJ) performance the following day [97]. Small or trivial correlations between changes in CMJ and CMJ with arm swing (CMJA) performance were found with respiratory sRPE (sRPEres) training load, muscular sRPE (sRPEmus) training load, and training volume [89]. These findings are in contrast with results highlighting a large negative correlation between volume and CMJA [92]. Single leg CMJ performance was also found to have a large negative correlation with sRPEmus-TL and the sum of sRPEmus-TL. However, squat jump (SJ) height has been reported to have a large positive correlation with single-leg sRPE training load ($r = 0.55$), despite sRPE only recording a small, statistically nonsignificant, positive correlation [98].

Changes in maximal sprinting speed have been found to have a moderate relationship with TD ($r = 0.46$), acceleration distance (AD) Load ($r = 0.57$) and heart rate exertion (HRE) ($r = 0.40$), while sRPE displayed an unclear relationship [95]. Changes in shorter sprint distance performances (i.e., 5 m and 15 m) vary from reporting small and trivial correlations with sRPEres-TL, sRPEmus-TL, and volume [89] to having large negative correlations with volume [89] and sRPEres measures [91].

Table 2.4. Summary of training load measures, interventions, and methodological approaches reporting the period assessed, training load metrics and performance evaluations utilized across the different studies.

Study	Period Assessed	Construct of Load	Training Load Measures	Performance Measures
Endurance Qualities				
Akubat et al. (2012)	6 weeks in-season	Internal	Training and match load measured using: - sRPE (AU) - Banister's TRIMP (AU) - Team TRIMP (AU) - iTRIMP (AU)	A modified lactate threshold test to determine velocity (km/h) and HR (bpm) at LT and OBLA in PRE & POST testing
Brink et al. (2010)	7 months in-season	Internal & External	Training and match load measured using: - Exposure (min) - sRPE (AU)	Submaximal ISRT was performed once a month to measure changes in HR (bpm) at 70% of max speed measured in pre-season
Cetolin et al. (2018)	8-weeks preseason	Internal	Training and friendly match load measured using: - sRPE (AU)	RSA test (best and mean) and Carminatti test performed PRE & POST
Fitzpatrick et al. (2018)	6 weeks in-season	Internal & External	Training load and match load measured using: - sRPE (AU) - Edward's TRIMP (AU) - TD (m) - HSD (>17km/h) (m & min) - VHSD (>21km/h) (m & min) - MAS (m & min) - 30ASR (m & min) - ACC and DEC Load (m >2m.s^{-2})	1500m time-trial to determine MAS performed PRE & POST
Gil-Rey et al. (2015)	9 weeks in-season	Internal & External	Training load and match load measured using: - Exposure (min) - sRPEmus (AU) - sRPEres (AU)	UMTT to determine the time to exhaustion (min) performed PRE & POST

Los Arcos et al. (2015)	9 weeks; 5 weeks preseason and 4 weeks in-season	Internal & External	Training load and match load measured using: - Exposure (min) - sRPEmus (AU) - sRPEres (AU)	A field based aerobic fitness test to determine Lac12, Lac13 and V3 in PRE and POST
Los Arcos et al. (2017)	32 weeks; 5 weeks preseason and 27 weeks	Internal & External	Training load and match load measured using: - Exposure (min) - sRPEmus (AU) - sRPEres (AU)	A field based aerobic fitness test to determine Lac12, Lac13 and V3 in PRE and POST
Neuromuscular Qualities				
Fitzpatrick et al. (2018)	6 weeks in-season	Internal & External	Training load and match load measured using: - sRPE (AU) - Edward's TRIMP (AU) - TD (m) - HSD (>17km/h) (m & min) - VHSD (>21km/h) (m & min) - MAS (m & min) - 30ASR (m & min) - ACC and DEC Load (m >2m.s^{-2})	PRE and POST assessment of 40m sprint test to determine MSS
Gil-Rey et al. (2015)	9 weeks in-season	Internal & External	Training load and match load measured using: - Exposure (min) - sRPEmus (AU) - sRPEres (AU)	PRE and POST assessment of CMJ (cm), CMJA (cm) and 5 and 15 m sprint (s)
Los Arcos et al. (2015)	9 weeks; 5 weeks preseason and 4 weeks in-season	Internal & External	Training load and match load measured using: - Exposure (min) - sRPEmus (AU) - sRPEres (AU)	PRE and POST assessment of CMJ (cm), CMJA (cm), CMJD (cm), CMJND (cm) and 5 and 15 m sprint (s)

Los Arcos et al. (2017)	32 weeks; 5 weeks preseason and 27 weeks	Internal & External	Training load and match load measured using: - Exposure (min) - sRPEmus (AU) - sRPEres (AU)	PRE and POST assessment of CMJ (cm), CMJA (cm) and 5 and 15 m sprint (s)
Malone et al. (2015)	1 week in-season	Internal & External	Training load measured using: - Training exposure (min) - TD (m) - HSR (>5.5 m.s^{-2}) (m) - HRmax% (min) - sRPE (AU)	CMJ (cm) was assessed daily, before and following each training session
Sams et al. (2018)	14 weeks in-season	Internal	Training load and match load measured using: - sRPE (AU)	Weighted SJ (cm) was performed at baseline and 4 hours before 18 league matches
Thorpe et al. (2015)	17-days in-season	External	Training load and match load measured using: - THIR (>14.4 km/h) (m)	PRE and POST assessment of CMJ (cm)

sRPE session rating of perceived exertion, AU arbitrary units, TRIMP Training Impulse, iTRIMP individualized training impulse, HR heart rate, LT lactate threshold, OBLA onset of blood lactate accumulation (4.0 mmol/L), PRE baseline test, POST test performed following study period, ISRT intermittent shuttle running test, TL training load, RSA repeated sprint ability, TD total distance, HSD high-speed distance, VHSD very high-speed distance, MAS maximum aerobic speed, 30ASR 30% anaerobic speed reserve, ACC acceleration, DEC deceleration, sRPEmus muscular rating of perceived exertion, sRPEres respiratory rating of perceived exertion, UMTT Université de Montreal track test, Lac12 blood lactate accumulation at 12 km/h, Lac13 blood lactate accumulation at 13 km/h, V3 running velocity associated with a blood lactate accumulation of 3 mmol/L, MSS maximal sprint speed, CMJ countermovement jump, CMJA countermovement jump with arm swing, CMJD countermovement jump with single dominant leg, CMJnD countermovement jump with single non-dominant leg, SJ squat jump, THIR total high-intensity-running distance.

Table 2.5. Summary of the dose-response relationship between training load and physical performance reporting the results of the correlations recorded in the 10 studies identified by the systematic review.

Study	**Dose-Response Relationship Reported**
Endurance Qualities	
Akubat et al. (2012)	▪ Change in vLT was largely correlated to mean weekly iTRIMP (r = 0.67; p = 0.04). ▪ No significant correlations were found between training and match loads (sRPE, Banister or Edwards TRIMP) against changes in LTHR, vOBLA or OBLAHR.
Brink et al. (2010)	▪ ISRT test performance outcome was significantly related to TLd 1-week (-0.9 bpm per every additional hour of training, p<0.05). ▪ TLd 2-weeks significantly predicted ISRT test performance outcome (-0.3 bpm per every additional hour of training, p<0.05) but did not significantly contribute to the model. ▪ sRPE-TL did not significantly contribute ISRT performance in the 1- or 2-week models.
Cetolin et al. (2018)	▪ Relationships between the total sRPE-TL and changes in RSAbest, RSAmean, and PVT-CAR were not significant in U15 (r = -0.19, p = 0.45; r = 0.02, p = 0.95; r = -0.05, p = 0.86 respectively) or U19 players (r = -0.26, p = 0.42; r = -0.27, p = 0.39; r = 0.52, p = 0.09 respectively). ▪ When data from both groups were pooled, a moderate negative correlation was found between the total sRPE-TL and changes in RSAmean (r = -0.36, p = 0.05).
Fitzpatrick et al. (2018)	▪ A very large linear relationship was found between t>MAS and changes in MAS (r = 0.77, 90% CI, 0.48 to 0.91). ▪ Large relationships were found between t>30ASR (r = 0.62, 90% CI, 0.22 to 0.84) and m>MAS (r = 0.50, 90% CI, 0.06 to 0.78) with changes in MAS. ▪ Unclear relationships were found between all other mean weekly arbitrary and individualized training external and internal load measures and changes in MAS (r between -0.07 and 0.37).
Gil-Rey et al. (2015)	▪ Changes in aerobic fitness levels (UMTT) are very largely and positively correlated with accumulated training and match sRPEres and sRPEmus (r = 0.71, CI (95%) 0.42 to 0.87 and r = 0.69, CI (95%) 0.40 to 0.85, respectively) when elite and non-elite players data are pooled. ▪ A large positive association was found between training and match volume and change in aerobic fitness (r = 0.67, CI (95%) 0.37 to 0.83).
Los Arcos et al. (2015)	▪ A large negative correlation was noted between sRPEmus and changes in aerobic performance (Lac13; r = -0.57, p<0.05). ▪ A small to moderate negative association was reported between practice volume and players endurance ability (Lac13; r = -0.37).
Los Arcos et al. (2017)	▪ Practice volume recorded large negative correlations with changes in aerobic parameters V3, Lac12 and Lac13 (r = -0.57, -0.62 and -0.61 respectively). ▪ sRPEres and sRPEmus had a large negative correlation with the changes in Lac13 (r = -0.61 and -0.55 respectively) and moderate to large correlation with V3 (r = -0.57 and -0.47 respectively).

Neuromuscular Qualities	
Fitzpatrick et al. (2018)	▪ TD (r = 0.46, 90% CI, 0.00 to 0.76), AD load (r = 0.57, 90% CI, 0.15 to 0.81), and Edwards TRIMP (r = 0.40, 90% CI, −0.07 to 0.73) were found to have a moderate to large relationship with changes in MSS. ▪ sRPE (r = 0.37, 90% CI, -0.11 to 0.71) displayed an unclear relationship with changes in MSS.
Gil-Rey et al. (2015)	▪ The correlations between changes in jump height (i.e., CMJ and CMJA) and sprinting performance (i.e., 5 and 15 m) with sRPEres, sRPEmus and practice volume were small to trivial (r ranging between -0.21 and 0.25).
Los Arcos et al. (2015)	▪ Total exposure had a large negative correlation with change in 5 m and 15 m sprint performance (r = 0.54 and r = 0.64 respectively) and CMJA (r = 0.51). ▪ Large negative correlations were found between both sRPEmus-TL, as well as the sum of RPEmus and change in CMJD and CMJnD performance (r = -0.61).
Los Arcos et al. (2017)	▪ Changes in 15 m sprint time correlated with sRPEres-TL (r = -0.53) and the sum of RPEres measures (r = -0.51) after 32 weeks of soccer training.
Malone et al. (2015)	▪ No significant correlations were found between absolute change in jump height and any of the internal or external training load variables (p > 0.269).
Sams et al. (2018)	▪ A large positive correlation was observed between single-lag sRPE-TL and changes in SJ height (r = 0.55, p = 0.02). ▪ A correlation between weekly sRPE-TL and changes in SJ height was observed to be small and statistically nonsignificant (r = 0.18, p = 0.48).
Thorpe et al. (2015)	▪ Changes in CMJ performance were correlated with THIR distance covered on the previous day (r = 0.23, small, p = 0.04).

vLT velocity at lactate threshold, iTRIMP individualized training impulse, LTHR heart rate at lactate threshold, vOBLA velocity at onset of blood lactate accumulation (4.0 mmol/L), OBLAHR heart rate at onset of blood lactate accumulation, TLd training duration, ISRT Intermittent shuttle running test, bpm beats per minute, sRPE session rating of perceived exertion, TL training load, RSAbest fastest sprint time recorded in the repeated-sprint ability test, RSAmean mean sprint time recorded in repeated-sprint ability test, PVT-CAR peak velocity derived from the Carminatti test, t>MAS time spent above maximum aerobic speed, MAS maximum aerobic speed, CI confidence intervals, t>30ASR time spent above 30% anaerobic speed reserve, m>MAS distance covered above maximum aerobic speed, UMTT Université de Montreal track test, sRPEres respiratory session rating of perceived exertion training load, sRPEmus muscular session rating of perceived exertion training load, Lac13 blood lactate accumulation at 13 km/h, V3 running velocity associated with a blood lactate accumulation of 3 mmol/L, Lac12 blood lactate accumulation at 12 km/h, TD total distance, AD acceleration and deceleration distance (>2m.s^{-2}), TRIMP training impulse, MSS maximal Sprint Speed, CMJ countermovement jump, CMJA countermovement jump with arm swing, CMJD countermovement jump with single dominant leg, CMJnD countermovement jump with single non-dominant leg, SJ squat jump, THIR Total high-intensity-running distance (>14.4 km/h).

2.4 Discussion

Investigating the dose-response relationship between training load and changes in youth soccer players physical capacity is critical to informing targeted exercise prescription which will optimise training outcomes. Whilst the risk of bias assessment low to moderate risk in the literature, the systematic analysis showed the finding were imprecise, inconsistent, and indirect. The findings highlighted that there is limited information available regarding the associations between changes in physical performance measures with both internal and external load measures in youth football research. In addition, relationships between endurance and neuromuscular capacity are inconsistent across different load measures in the available literature.

Protocols to Measure the Response

In youth soccer, changes in players endurance capacity are commonly assessed. Tests of endurance capacity reflect the prevalence of aerobically-derived energy sources in supporting the prolonged, high-intensity intermittent exercise performance [63] and the ability to sustain exercise intensities of 80-90% maximum HR (HRmax) and 70-80% of maximal oxygen consumption (VO_2max), which are common in match play [8, 43, 99]. Player's endurance capacity was assessed in seven out of ten studies included in this systematic review, utilizing a wide range of different physical assessments (both continuous [89, 91-93, 95] and intermittent [90, 94]) and employing them at different times within a competitive season. Possible reasons for the variety of different test protocols reported in the studies may be due to the numerous different aspects contributing to physical performance [63] and the range of methods available to assess these factors. We recommend that practitioners select endurance capacity tests based on the feasibility and measurement characteristics (i.e., validity, reliability, and sensitivity) utilized, as this is the aspect that is essential to effectively record changes in players physical performance levels [8, 51, 100, 101]. In this review, four of the seven articles assessing this quality employed submaximal test protocols (one of which was lab-based [93]), concentrating on measuring changes in specific physiological thresholds (e.g. lactate and anaerobic threshold) [91-93] or HR responses [90] to assess the variations in players endurance capacity. One study suggested that the intermittent nature of the game ought to be taken into consideration for a test to be sport-specific [93], however, this does not necessarily facilitate the assessment of player's aerobic characteristics in isolation from other physical factors. Difficulties relating to the requirement for maximal efforts and player's motivation to perform them limit the feasibility of using many common field tests during the in-season period and favours the use of submaximal test protocols in football populations (e.g., continuous constant speed and intermittent running evaluations) [90, 102]. Player's neuromuscular capacity (i.e., strength and power) were also evaluated in seven studies, each using a variety of jump test protocols [89, 91, 92, 96-98] and/or sprint tests [89, 91, 92, 95]. Like the endurance tests, there were large differences in the frequency and timing of testing, varying from daily or weekly to a 32-week training block which makes accurate comparison difficult. The jump protocols utilized included countermovement jumps with and without arm-swing, single-leg jumps, as well as weighted jump protocols. While sprint tests ranged from 5 to 40 m distances to assess "sport-specific speed" or maximal sprinting speed. Greater standardization of the testing protocols applied (i.e., which sprint distance or jump protocol to utilize) is key to helping practitioners and researchers identify measures that can effectively provide practical insights for the monitoring process.

Exposure

Exposure vs. Endurance

Training exposure represents the simplest measure regarding the quantity of training performed by the players. The impact of both training and match volume on youth players physical qualities was investigated in four studies, with three studies showing positive relationships with endurance adaptations. A greater training duration in the week before a test was associated with greater improvements in intermittent shuttle running performance in 18 young elite players during in-season testing [90]. A large positive association was also observed between the training and match volume accumulated over a 9-week in-season period and aerobic fitness levels in 28 (elite and non-elite) youth players [89]. This however was not reflected following 9 weeks comprising 5 weeks of pre-season [92], as only a small non-significant negative association was observed between practice volume and players blood lactate accumulation during a continuous running test. These results suggest that the physical responses to an increased volume of training may be not consistent across different periods of the season.

Only one study assessed relationships over a long period (32 weeks, including 5 weeks pre-season) reporting a moderate, negative association between exposure and aerobic fitness parameters (blood lactate accumulation) in 14 young professional Spanish players [91]. This observation supports the importance of the continuity of training and match exposure to achieve improvements in endurance performance. However, this may also be influenced by how the players achieved their total exposure, as the individual players will have had different training and match exposures across the 8 months. The limited number of players and variability observed in the correlation (r = 0.62 ± 0.31 (90% confidence intervals)) may also have been influenced by factors relating to the periodization of training and match exposure across the 32 weeks.

In general, the limited number of studies that have systematically assessed the relationship between exposure and changes in endurance performance appear to support the existence of an association. Three studies reported a positive relationship [89-91] and one reported a small, non-significant, impact on player's endurance capacity [92]. However, it must be considered that the context, training status, and stage of the competitive season may influence the acute and chronic physical adaptations recorded. The use of different time frames and periods of the competitive season also makes comparison between studies difficult; a greater standardization of the test periods and reporting of longitudinal load data is required. Further studies are required to evaluate the nature of the association with exposure, how these change across a competitive season, and the relative impact of both training and match play on the physical outcome.

Exposure vs. Neuromuscular Performance

The dose-response relationship between training and competition exposure and neuromuscular performance has been assessed by four studies. Like endurance test measures, there is also a lack of standardisation in the test methods used to assess neuromuscular quality between the studies. Nonetheless, three studies reported no significant correlations between exposure and countermovement jump height (r values ranging between -0.21 and 0.36) [89, 91, 96] or sprint performance (r values ranging between -0.23 and 0.23) [89, 91]. However, one study reported higher training volumes to have a large negative association with both short sprint performance (5 and 15 m) and countermovement jump height (with arm-swing) [92]. In this previous study [92], the test session was performed 4 weeks following the end of the pre-season period, in which high training volumes and overall sRPE load were performed, suggesting that large training volumes are counterproductive to the development of “explosive” neuromuscular characteristics. However, the inconsistency in the relationships between the various measures derived from the three different jump protocols utilized in this study [92] warrants caution in the interpretation of the data.

The volume of soccer training performed may not be a good indicator of the quantity or quality of the neuromuscular stimulus the players are exposed. A high volume may induce a fatiguing effect and contribute to a negative relationship, and therefore the dose-response relationship may not be linear. Whilst it is acknowledged that it is difficult to provide strong recommendations from the limited evidence available, it appears that the player's training exposure during in-season phases does not lead to marked changes in jump or sprint performance.

Internal Load

RPE vs. Endurance

The present systematic analysis of the literature showed that the youth soccer player's internal training load, calculated using the sRPE method [78, 79], demonstrated inconsistent findings with training-induced changes in endurance ability. The changes recorded in players submaximal continuous [93] or intermittent [90, 94] running capacity showed no significant correlations with sRPE training load during either the preseason [94] or in-season [90]. Others reported unclear relationships with changes in maximal aerobic speed performance following 6 weeks of in-season training [95]. A possible explanation for the unclear relationships is that RPE measures fall within a small range on the scale (e.g. 14.3 arbitrary units (AU) and 14.4 AU on a 6-20 RPE scale across the two successive weeks of training, respectively) [90], and greater differentiation of individual responses may be required to better evaluate a dose-response relationship. These findings reflect the limited variation in sRPE load observed across four or six-week mesocycles in elite adult players [40, 103]. To date, there is limited evidence relating to the average RPE scores recorded by youth soccer players or describing the variation in training load between weeks or different periods of the season.

Cetolin et al. [94] was the only study to evaluate the dose-response relationships with intermittent running performance (i.e., Carminatti Test (T-CAR) & RSA) across two different age groups (i.e., U15 and U 19) within the same youth academy. Similar to previous findings [36], the two age groups were exposed to different levels of load, with U19 players accumulating significantly greater total training load values (sRPE-TL) than the U15 players. This was influenced by the U19 players perceiving sessions to be more intense across the 8 weeks of pre-season training (i.e., higher average RPE scores; 6.1 vs 5.3 for U19 and U15 respectively on a category ratio scale (CR10)) [94]. In this study, no significant correlation was observed in either age category between RPE-based TL and changes in endurance performance. However, when data were pooled from the two different age groups (n = 30), a moderate negative correlation between sRPE-TL and the player's repeated-sprint ability (RSA mean; r = -0.36) [94]. Despite the lower weekly loads, the U15 players recorded superior gains in endurance performance tests (i.e., RSA and T-CAR). This finding shows that there may be different dose-response relationships between players of different age groups, as the U15 players may require a lower training stimulus (i.e., lower weekly loads) to obtain the desired improvements in endurance performance capacity. The higher levels of load recorded in the U19 players appear not to be optimal for improving these capacities. This may be due to maladaptive training (i.e., overreaching) or inappropriate training content. However, the assessment of individual player's adaptation to the training, instead of group-based evaluations, appears to be necessary to gain a better understanding of the existence and/or strength of the dose-response relationships.

Differential RPE vs. Endurance

Differential RPE scores have been applied to evaluate players central and local effort separately [104-106]. In elite and non-elite level youth players large and very large correlations were observed for total respiratory (sRPEres-TL) and muscular exertion (sRPEres-TL) training load with changes in aerobic fitness levels during a 9-week in-season period [89]. Large negative associations (i.e., impaired performance) were also observed between submaximal lactate production and the sRPEres-TL and sRPEmus-TL accumulated over 32 weeks [91]. However, a study evaluating 9-weeks of training that included both the pre-season and in-season periods [92] found higher sRPEres-TL to have a positive effect on the players aerobic fitness. However, the association with sRPEmus-TL is influenced by running intensity, as no significant relationship was observed at the lower speed threshold (blood lactate accumulation at 12 km/h (Lac12)). Furthermore, there was no significant dose-response relationship observed between changes in blood lactate accumulation during a submaximal continuous running protocol the sum of all muscular or respiratory efforts [92].

There is a lack of consistency in findings of the dose-response relationship and various RPE-derived measures of training load and endurance capacity. The differences reported between studies may be due to the lack of consistency in the scale utilized to collect the RPE scores (Borg 6-20 scale, Borg CR10 scale, or differential measures). Despite the different RPE scales being highly related to each other and other physiological measures (e.g., HR intensity) [107, 108] the use of diverse scales renders comparison between the studies difficult. The limited number of subjects also influences the nature and strength of the relationships recorded.

Another aspect that might explain the differences in the relationships reported in these studies is the amount of absolute load accrued during the periods assessed. Gil-Rey et al. [89] reported that the sRPE load accumulated during the 9 weeks of their study is considerably lower compared to previous studies [36, 51, 78, 93]. While Los Arcos et al., [92] suggested that an “excessive” accumulation of training loads (sRPE) may induce reductions in player's endurance capacity, (i.e., the players were overreached). These differences in levels of load may impact the physical adaptations observed, as the range of training loads may be describing different sections of a curvilinear “inverted-U” dose-response relationship [109], where the insufficient or excessive load does not contribute towards optimal improvements in endurance performance. This implies that there could be a range of training exposure that elicits positive adaptations, after which point there is a decline in physical performance levels. However, accurate comparison between the studies remains difficult as there are different RPE scales used and different observation periods between these studies.

The evaluation of training frequency and distribution [75] over longer periods of the season may be affected by the greater quantity of load accumulated during matches [36, 42], differences between starters and non-starters [41, 110], as well as the prescription of recovery sessions or post-match fatigue [111-113]. We, therefore, recommend that relationships between training load and performance outcomes should be assessed over shorter periods (i.e.., 1-week of 4 weeks) or distinct phases of the season (e.g., pre-season vs in-season or training cycles with clear objectives). As weekly sRPEres-TL and sRPEmus-TL can be substantially higher during pre-season, due to a higher training frequency compared to the in-season period [92]. In addition, we recommended that the relationships should be assessed on an individual level (or account for individual player characteristics with mixed models), as there is a myriad of factors that can influence players training loads and the physical adaptations induced.

Taken collectively, the relationship between RPE load and endurance performance is unclear. Comparing findings in current literature is difficult due to the wide range of different methods and test protocols applied, as well as the different periods of the season, and methods for quantifying training load. The assessment of age-related differences within the youth academy requires further investigation. The distribution of the RPE load within the discrete period assessed may also warrant further investigation as little variation in levels may influence the strength of the variations observed.

HR vs. Endurance

In professional senior soccer players, the HR-derived loads during training and match play have been reported to have a positive correlation with changes in aerobic fitness levels [81-83]. However, there is currently little information available regarding the quantity or intensity of HR-derived load performed and changes in youth soccer player's physical performance levels. Only one study set out to specifically assess this relationship, by verifying the relationships between various HR-derived TRIMP measures (i.e., Banister’s, Team, and Individualized TRIMP, respectively) and changes in performance in nine 17 y old professional players following 6 weeks of in-season training [93]. The results highlighted that individualized thresholds (iTRIMP) [114] were correlated with changes in velocity at the lactate threshold (2 mmol$\cdot$L^{-1}). However, Banister’s and Team TRIMP measures were not associated with changes in player's endurance performance levels. Similarly, others have reported that the Edwards TRIMP was also found not to relate to changes in endurance ability in another cohort of professional junior players [95]. Although there is limited information available, the collective findings of these studies highlight that HR-based training load measures cannot be utilized interchangeably as they do not provide the same quantification of the dose performed or strength of relationship with performance response measures. Additionally, although limited, these findings support adopting an individualized approach to HR monitoring [93], as it accounted for inter-player differences in response to exercise. Further investigations are required to confirm these observations, with studies that have greater sample sizes and standardised measures of load and outcome measures.

A further notable observation from this study was that the positive correlation described for iTRIMP was not found at the higher intensity speed threshold investigated (velocity at an accumulation of blood lactate of 4.0 mmol/L^{-1}; vOBLA) [93]. This finding is in contrast to correlations previously reported between iTRIMP and VO_2max or yo-yo intermittent recovery level 1 (YYIRT1) performance in professional soccer players [83]. However, a similar trend had been observed in elite adult soccer players following the pre-season period [81, 82], with time spent above 90% HRmax noted to have a stronger correlation with changes in velocity at lactate threshold (vLT) than the higher threshold of vOBLA. Establishing the transferability of dose-response relationships observed in adult players to young players is essential, as this information may further our understanding of load management in this specific population and help to improve the training prescription process across the different age groups. In general, this area remains understudied, with limited evidence available and low power of associations reported. The use of different TRIMP methods within the same studies appears to indicate that the practitioners have yet to determine which HR-derived measure has the best association, if any, with outcome measures and ought to be monitored systematically. This use of different TRIMP measure also makes it difficult to compare studies and contributes to some of the inconsistencies observed.

RPE and Differential RPE vs. Jump Performance

sRPE and differential RPE training load measures were also utilized to evaluate the association with changes in neuromuscular performance. Two studies have shown that sRPE and differential RPE scores have only a weak relationship (r = -0.17 - 0.25) with changes in CMJ performance [89, 96]. This relationship may however be influenced by the limited changes in CMJ performance observed following a single training session [96] or over 9 weeks in trained athletes [89]. While no significant relationship was observed over a longer period comprising both pre-season and in-season (32 weeks) [91]. These differences in study design may influence the outcome and need to be aimed to answer the specific question regarding the exitance of a dose-response relationship. For example, the monitoring of changes in CMJ following a single training session [96, 97] may be deemed as an acute physical response to the dose, as opposed to a long-term physiological adaptation induced following an extended and repeated training stimulus [115]. In addition, it may be recommended that the relationships be assessed on an individual level, and identify the relationship between acute loads (i.e., 1 week) and chronic loads (i.e., 4 weeks) separately. The physical outcome associated with the load performed may also be influenced by the individual player's habitual training levels, we, therefore, encourage researchers to control for individual factors, as these may influence the relationship between training load and training outcomes.

Several associations recorded between RPE load measures and jump performance may also be specific to the nature of the outcome test (i.e., protocol dependent). For example, single leg jump performance was impaired by a greater sRPEmus over 9 weeks comprising both pre-season and in-season periods [92], while the sum of sRPEres accumulated over 32 weeks positively influenced countermovement jump with arm-swing performance [91]. Differences can also be observed within single load constructs, for example, no correlation was recorded between squat jump height and sRPE over 14 weeks in-season, while a time-lagged TL (using a cross-correlation coefficient) was found to have a statistically significant positive correlation for the same period [98]. The absence of consistent correlations between the RPE TL and change in youth players neuromuscular performance may be due to the diversity of load measures, periods of the season, and physical evaluations applied to examine this relationship. However, this may also be due to the lack of relevance of the selected load measures used in previous studies. Indeed, we suggest that practitioners ought to examine the different training load constructs according to a specific performance framework. For example, it may be more appropriate to assess training doses specific to stimulating the physiological capacity of interest according to an evidence-informed framework. The development of a conceptual framework can aid practitioners in the selection of appropriate load constructs for each performance measure and facilitate the interpretation of the data about their influence on changes in outcome measures. There is some evidence to indicate that this is a process already occurring, as two studies indicated that the lack of associations found may be due to load management within weekly training micro-cycles [96], as well as across longer periods for fatigue management or preserving players deemed at risk of injury [98]. Both studies were conducted in-season and highlighted maintenance of players neuromuscular performance levels as a goal for the athlete monitoring program, with the main body of training focused on tactical aspects, as opposed to creating a physiological overload for the players [96].

Conceptually, it is logical that football players develop physical capacities during the preseason period and maintain these during the competitive season [35, 40]. The concept of "maintenance" of neuromuscular capacity during specific periods of the competitive season further supports the analysis of pre- and in-season periods separately, as well as focusing on shorter training periods that aim to achieve different physical goals. However, this approach may be specific to adult players, as youth players may continue to develop during the season, supported by a physical maturation process [15]. To date, no study has examined the contribution of the training dose to explain changes in physical capacity over longer periods, thereby evaluating youth players long-term development [7, 116], stratifying for age within the youth academy, or performing a longitudinal evaluation.

RPE and Differential RPE vs. Sprint Performance

Three studies have reported the relationship between RPE-derived training load measures and changes in sprint performance, with inconsistent findings [89, 91, 92]. Over short sprint distances (i.e., 5-15 m) the accumulation of higher levels of training volume [91] and respiratory RPE training load measures [89] were found to have a large negative association with performance. Over longer sprint distances (40-m) sRPE training load showed an unclear relationship with performance. Like jump performance, negligible changes in performance (i.e., a focus on maintenance of neuromuscular capacity) during the period assessed may be partially responsible for the small to trivial correlations observed during the in-season period [89, 95].

The associations between load and neuromuscular performance outcomes are under-investigated and the use of different internal load measures and sprint distances makes the comparison between studies difficult. The negative correlations were found for two different measures of internal load and the periods assessed also differed (9 weeks in-season vs. 32 weeks comprising the pre-season). It may be that the relationship is influenced by the presence of fatigue, where higher levels of perceived exertion negatively influence players neuromuscular freshness. The assessment of a dose-response relationship is recommended over both shorter and longer periods to assess the acute and chronic effects of training. Furthermore, it must also be acknowledged that not all load measures will necessarily correlate with performance in a conceptual framework for performance in youth soccer players.

HR vs. Sprint Performance

Only one study assessed the relationship between a HR variable and sprint performance. Edwards TRIMP was found to have a non-significant moderate correlation with maximal sprinting speed [95] following 6 weeks of in-season training. This aspect appears to be under-investigated, particularly when considering the wide range of HR measures applied to examine the association with endurance performance. However, this may be due to the differences in constructs of load being monitored and assessed. To date, no studies have evaluated the potential differences between different age groups within the youth academy and how these impact the relationship between HR intensity with sprint capacity.

External Load

External load vs. Endurance

Despite the increased availability and utilization of wearable technology [23] only three studies have investigated the existence of a dose-response relationship with endurance capacity utilizing external load measures in elite youth players. Additionally, the few studies that have investigated this relationship have used a range of different absolute and relative training load measures.

With regards to aerobic fitness levels, a very large correlation was found between training time spent above MAS and changes in aerobic fitness in 14 professional junior soccer players following 6 weeks of in-season training [95]. Distance covered in training and matches above the MAS threshold also presented a large association with changes in endurance capacity (assessed via a field-based 1500 m running time-trial), but not as strong as relationships observed for time. Interestingly the positive correlation reported was found to be less strong at a higher threshold (above 30% of anaerobic speed reserve, calculated as the difference between MAS and maximal sprinting speed, r = 0.62). The distance covered and time spent above arbitrary thresholds (i.e. 17 and 21 km/h, respectively) [95] in training did not present any correlations with changes in endurance performance. Although preliminary, these findings support the use of individualized high-intensity speed thresholds based on physiological characteristics. While this finding is important for the evaluation of which external load variables contribute toward a dose-response relationship, it is specific to one study and observed with a continuous maximal running test. Further research is required to verify this association and confirm if it exists with other sport-specific endurance performance tests (e.g., submaximal, and intermittent running evaluations).

A practical limitation with the use of individualized thresholds to determine individual training load profiles of youth football players is the requirement to regularly assess and adjust individual player algorithms for change in physiological capabilities (and resultant threshold values). Indeed, the changes in lactate thresholds during adolescence and soccer season have been widely observed [51, 117], and therefore this requirement reduces the practical utility of this approach.

External load vs. Jump and Sprint Performance

External training load variables and metrics have also been investigated for their relationship to training-induced changes in neuromuscular performance in three studies. Like endurance ability there is very limited information available on these purported relationships, despite the widespread use of wearable technology. Total distance and high-intensity running distance, quantified using distance covered above an absolute threshold ($>5.5\ m \cdot s^{-1}$), were found not to impact CMJ performance [96] in 9 professional youth players. The findings from this single study showed that load performed during sessions from a typical in-season training week may not be sufficient to induce stress/fatigue levels to the extent that would alter their neuromuscular performance. An important aspect of this study was that players were required to perform the CMJ test 5 minutes following the end of each training session, which helps to exclude the possibility that players were “recovered” from training-induced fatigue before the evaluation. This finding contrasts with another report, where the quantity of high-speed running performed during in-season training (i.e., distance travelled >14.4 km/h) was found to significantly impact CMJ performance the following day ($r = 0.23$) in 10 elite youth players. This dose-response relationship in this previous study was observed over a 17-day in-season period with standard weekly micro-cycles (1 competitive match per week). To date, no studies have evaluated the influence of external training load metrics on youth soccer players CMJ performance over longer periods.

Moderate to large relationships between various external training load metrics and changes in 40-m sprint performance (i.e., TD (m) and ACC and DEC load (r = 0.46, 0.57, and 0.40, respectively) in 14 professional junior players [95]. These observations suggest that both volume and quantity of muscular load performed during training (i.e., the number of ACC, DEC, and quantity of very high-speed running (VHSR)) may contribute toward players maximal sprinting speed. However, further studies are required to determine which measures of load influence neuromuscular performance, over acute and chronic training periods. The nature of team sports training and positional differences make it difficult to ensure an appropriate level of training stimulus for each player [118] and increasingly important to have a better understanding of the physical responses that can be expected.

Overall, the summary of dose-response relationships specific to a youth soccer population highlights the broad selection of training load measures and metrics that have been utilized by the different teams and research groups. This observation is in line with a recent study evaluating the load measures utilized across 41 elite-level soccer teams [26], reporting the use of a large range of training load parameters and a lack of consistency in the selection of time-motion thresholds utilized in different clubs. Furthermore, given that time-motion analysis using GPS units was the most popular method used to quantify load [26], it is surprising that so few studies have assessed the relationship between these measures and changes in physical performance measures. The wide range of parameters utilized may also be due to the different constructs of load (both internal and external [75]) and training modes (field-based or gym-based sessions) that have to be implemented to prepare youth soccer players. This review highlights both the lack of consistency in load measures and physical outcome measures applied in youth soccer. The few available studies that have reported relationships between dose-response over different periods of the season also make it difficult to provide insights regarding appropriate loading schemes. This process may be improved following a sound conceptual framework for selecting load constructs.

Two previous systematic reviews have investigated the influence of load on performance in team sports [80] and professional soccer [58] (including 26 and 12 studies, respectively). Both support HR-based training load to be positively associated with changes in aerobic fitness levels, however, the evidence for this in soccer was limited to the high-intensity internal load accrued during the preseason phase [58]. The level of evidence available for this association is even more limited in youth soccer. Furthermore, despite the widespread use of sRPE method for the quantification of load, there are inconsistent findings and limited evidence concerning its relationship with physical outcomes, injury, and illness in team sports or soccer [58, 80]. Evaluating the players internal responses is of particular importance given the intermittent nature of efforts and their role in mediating the physical adaptations [75]. This framework is further supported by the improvements in players endurance abilities observed following high levels of HRE (using individualized thresholds). Interestingly for the training process, these changes in players physical condition can be elicited during both generic interval training and small-sided games [51], despite accruing different external and muscular loads.

To date, little evidence is available regarding the existence of an association between external load and neuromuscular performance (CMJ and Sprint) [58]. More studies are required to improve the confidence with which practitioners can prescribe load measures to model performance, particularly in this specific population.

This systematic review aimed to examine the information available in current literature regarding the existence of a dose-response relationship between training load and physical performance in youth soccer players. The results further confirm recent observations that there are very few studies examining these relationships using the data recorded by wearable player tracking technology in soccer (e.g., GPS and accelerometers) [58]. Whilst we found low to moderate risk of bias in current studies, we also observed their findings were imprecise, inconsistent, and indirect. The limited information available is influenced by the diverse training load measures and physical assessments utilized across the different studies. It appears that studies tend to investigate single load measures or constructs of load for a relationship with changes in performance. Additionally, there has been a lack of standardisation on the periods of training that are used to associate training load measures with outcomes measures in previous studies. It would be advantageous if standard periods for reporting load were used to assess any relationships with outcome measures. Indeed, a recent study on adult professional soccer players (Martini et al., 2022) used both acute (i.e., 1 week) and chronic periods (4 weeks) to assess associations with aerobic capacity and training load metrics. This approach seems logical as it aligns with common conceptual models of training adaptation (i.e., Banister's fitness-fatigue model) [119]. To date, the differences between age groups within youth academies have not been well described. Future research should attempt to identify which load measure can effectively contribute toward improvements in player performance (both endurance and neuromuscular) and the consistency of these relationships across different periods of a competitive season using standardised load reporting periods.

It has been well documented that soccer match results are not solely dependent on physical performance factors, due to the importance of technical and tactical aspects [120, 121]. However, the practitioners aim remains that of developing an integrated approach for the prescription of workloads, in collaboration with the technical staff, which can facilitate positive training adaptations and player's readiness to perform. At present, there is uncertainty regarding which load variable is the most “valid” for monitoring training load and its association with physical performance. Indeed, it is likely that the most appropriate load variable will depend on a myriad of contextual factors. However, further studies are required to better understand the dose-response relationship between training load and fitness outcome measures. Such information is critical to developing an evidence-based approach to the planning and/or assessment of the training process.

A conceptual framework can provide a more detailed description of the different constructs of load (i.e., both internal and external) and how their relationships are mapped with specific outcome measures (e.g., endurance or neuromuscular). Therefore, facilitating the description of loads that youth soccer players experience during training and matches and the selection of variables to be included in the analysis. The large number of metrics and thresholds that are readily available often complicate data analysis and identifying the signal from the noise in load monitoring data. The reduction of metrics being evaluated, based on a conceptual framework, can simplify the assessment of dose-response relationships. Future studies need to overcome the limitations of previous studies to better determine the relationships with outcome measures. This includes low sample sizes, inconsistent periods of the season, and a selection of variables not based on a conceptual framework.

The original studies retained in this systematic review also suggested that future studies should examine longer periods, different levels of load, a more detailed evaluation of the technical-tactical training performed and specifically assess individual responses [40, 52, 60, 93]. Every piece of the puzzle can contribute towards an increased understanding of the training load modelling strategy to be applied and the physiological response it elicits in soccer players, particularly important when considering the prescription of age-specific soccer training and the development of youth players. This information can aid practitioners to establish a more proactive approach to training load programming, helping the fine-tuning of the individual training loads, as opposed to a reactive response in post-analysis.

CHAPTER THREE

Study Two: How do young soccer players train? A 5-year analysis of weekly training load and its variability in an elite youth academy

Chapter preface

This study described the levels of sRPE training load being performed by the different age groups of an elite youth soccer academy to frame the differences in the demands. This was performed to provide a perspective of the progression across the age groups and differences between levels being recorded by starters and non-starters. Results revealed a consistent pattern of training load distribution with limited variation between the in-season training weeks. Additionally, the findings that support the differentiation of RPE and session duration in the player monitoring process can help practitioners to assess individual differences.

3.1 Introduction

The quantification of individual athletes' training load and their responses to that load is common practice in many elite-level football clubs, including youth academies [18]. Indeed, a high priority for sports scientists working in youth academies is to quantify and control the training dose prescribed to the players, to optimise player performance and health. Training load control is achieved through careful manipulation of training prescription variables: frequency, intensity, duration, and mode [20]. The monitoring of load variables and the integration of additional contextual factors (i.e., fitness, performance indicators, athlete perceptions, etc.) can be utilized to assess the effectiveness of the periodized training strategies applied and inform decisions relating to the training program.

The training process framework, a conceptual model introduced to guide the development of athlete monitoring systems, describes the athlete's training dose in two distinct categories: internal and external load [62]. External load is the result of the frequency, intensity, and quantity of load completed by the athlete, measured independently of the player's characteristics or fitness levels, while the internal load refers to the psycho-physiological stress induced directly from the external load completed. The sRPE method is a simple, inexpensive, and non-invasive method for monitoring internal training load that has been validated for monitoring soccer players [25, 122]. This method provides a measure of intensity that is influenced by many different factors, including cardiovascular load [123, 124] and mental and muscular fatigue [125, 126]. sRPE overcomes limitations of other internal load measures as it allows for continuity of data collection (i.e., low risk of data loss) and can be applied across all training modes (e.g., technical-tactical training sessions, gym-based sessions, and match play) and training locations.

Several recent studies have described the training periodization strategies applied in elite-level soccer [39, 40, 42, 127-129]. Specifically, these case studies have described the periodised training strategies applied within a training micro-cycle structure, providing new insights into the quantity and distribution of training load in elite and sub-elite professional adult players (age range: 20–27 y). However, despite the widespread use of athlete monitoring in elite football academies, only a few studies have described the training characteristics of elite youth soccer players [15, 36, 37]. These have assessed in-season weekly training load from one period of a specific season (e.g., the start of the season [36], the second half of the season [37], or across the entire season [15]) with a limited sample size per each age group, reporting different measures of load across different micro-cycle structures between the different age groups. Consequently, the training characteristics of elite youth soccer players and the differences between age groups have yet to be fully established. Obtaining a better understanding of these characteristics the volume, intensity, and distribution of training load that elite youth players experience as they progress through football academies is particularly important as it can inform the development of appropriate training plans.

Information relating specifically to youth players is critical as findings recorded by adult players [39, 40, 42, 129] may not be suited to younger, less mature players [130]. Gaining a greater understanding of the differences between youth and senior players can aid training programming for these specific age groups. Of the few studies that have investigated youth players, it was shown that older age groups (i.e. U18) are exposed to greater levels of load (volume, weekly sRPE, and time >90% HRmax) than younger age groups [36]. These differences in youth players accumulated weekly load have been attributed, at least in part, to different technical-tactical requirements across the different age groups [37, 64] and differences in coach's training styles [131]. Several studies have reported the typical within-week micro-cycle distribution of training loads and across longer periods of the competitive season in elite adult players [39, 40, 42]. These studies showed a consistent pattern of distribution within weekly training micro-cycles but with little variation between weeks. Similarly, limited variations in mean weekly duration and distance have been observed in elite youth soccer premier players [15]. However, clear differences have also been observed between different English Premier League academies, likely related to training philosophies and organization between clubs [15]. The limited variations observed may be due to planning constraints and potentially limit player's adaptive responses. Others have highlighted that starters experience greater training loads than non-starters in-season, particularly during congested periods in both adult [128, 132] and youth players [110]. However, at present, it is not known if non-starting players in elite youth academies record different training characteristics when compared to starters. Furthering our knowledge relating to these differences is important for the development of individual training plans that integrate the missing match load to ensure training adaptations and continue to promote the long-term development of all players within the squad.

Information regarding the nature, volume, and intensity of the training performed can facilitate the optimization of a training plan for individual players [22, 133] by helping to inform programmatic decisions. At present, there are few reports regarding the training characteristics of elite youth soccer players, and many of the current studies have been limited by low sample sizes and the relatively short periods of a specific season. Therefore, this study aimed to quantify the perceived intensity (sRPE) and duration of the training and competition load performed by elite youth level soccer players (U15 to U19 age groups) from a top-level soccer academy over five consecutive seasons. Secondary aims were to quantify the differences between starters compared to non-starters in the different age groups and describe the variation of training load variables (sRPE, duration, and training load) recorded across an entire competitive season.

3.2 Methods

Experimental Approach to the Problem

This study was conducted utilizing mixed models to assess the levels of load accrued by elite youth soccer players across a whole training week, stratifying the data for age group and playing status. Each player's data was recorded during training and matches, as part of a systematic player monitoring program, across all periods of 5 competitive seasons (from 2014-15 to 2018-19). For this descriptive analysis, player's mean weekly sRPE scores, total weekly training duration, and total weekly sRPE-training load data [79] were assessed to ascertain the within (i.e., starter vs non-starter) and between-group differences across 4 different age groups.

Subjects

Elite youth level soccer players from the U15, U16, U17, and U19 teams of the same elite level Italian soccer academy participated in this study. A total of 230 unique players completed all training and matches (if scheduled), in at least one in-season week, to be eligible for inclusion. Forty-one of these players appear as repeat measures across the different seasons as they progress across the different age groups of the academy. A written consent form was obtained from each subject and their legal guardian before the commencement of the study. The player’s anthropometric measures are presented in Table 3.1. The study was approved by the University Research Ethics Committee (UTS HREC ETH19-4420).

Table 3.1. Player's anthropometric measurements across 5 competitive seasons (mean ± SD).

	2014-2015	**2015-2016**	**2016-2017**	**2017-2018**	**2018-2019**
Under 15					
n	21	18	22	23	23
Age (y)	14.4 ± 0.3	14.4 ± 0.2	14.4 ± 0.3	14.3 ± 0.3	14.4 ± 0.3
Height (m)	1.75 ± 0.07	1.74 ± 0.07	1.72 ± 0.07	1.71 ± 0.07	1.71 ± 0.07
Body mass (kg)	60.7 ± 7.7	58.5 ± 6.8	60.3 ± 7.6	56.9 ± 8.1	60.1 ± 7.0
Under 16					
n	25	19	19	22	23
Age (y)	15.4 ± 0.2	15.4 ± 0.3	15.4 ± 0.3	15.3 ± 0.2	15.4 ± 0.3
Height (m)	1.76 ± 0.07	1.78 ± 0.07	1.77 ± 0.05	1.75 ± 0.05	1.76 ± 0.07
Body mass (kg)	65.5 ± 6.9	64.6 ± 6.1	65.3 ± 5.6	65.7 ± 6.1	66.0 ± 6.6
Under 17					
n	20	19	19	22	24
Age (y)	16.3 ± 0.3	16.3 ± 0.4	16.4 ± 0.5	16.3 ± 0.4	16.4 ± 0.2
Height (m)	1.79 ± 0.05	1.80 ± 0.07	1.78 ± 0.08	1.77 ± 0.04	1.79 ± 0.05
Body mass (kg)	68.3 ± 5.4	70.7 ± 6.8	69.0 ± 7.7	69.8 ± 5.5	69.0 ± 5.0
Under 19					
n	27	25	27	31	27
Age (y)	17.5 ± 0.6	18.0 ± 0.7	18.1 ± 0.8	17.9 ± 0.8	17.8 ± 0.6
Height (m)	1.81 ± 0.05	1.80 ± 0.06	1.80 ± 0.05	1.79 ± 0.05	1.80 ± 0.05
Body mass (kg)	74.2 ± 5.4	74.2 ± 7.0	73.7 ± 6.2	73.1 ± 5.5	73.5 ± 4.9

Procedures

Individual player's perceived exertion was recorded using the sRPE method, measured using Borg's CR10 scale [79, 134]. All players were familiarized with the validated Italian translation of the Borg Scale [25] during a lesson dedicated to explaining this method and its correct use before commencing the study, this sensitization process was repeated with all players at the beginning of each competitive season. The player's sRPE value was collected manually from each player independently (i.e., free from coaches and other players influence) ~30 min following each training session and match performed across all four age groups. To help ensure a continued verification of players understanding and use of the sRPE scale each team's fitness coach continuously requested that the players quantify their perception of effort in accordance with the visual anchors provided on the scale. When new players enter the club, a greater emphasis was placed on guaranteeing their understanding of the monitoring process, including the recording of their subjective measures. The internal load (sRPE-training load) of each session was subsequently calculated by multiplying the players sRPE by the duration of the session [79]. Where the duration of each session refers to the time (minutes) elapsed from the initiation of warm-up to the end of the event (training or match).

The data from players who completed the whole in-season training week (typically four pitch-based technical-tactical training sessions, one gym-based session, and a competitive match) was utilized for the analysis, calculating the mean sRPE value and sum of total weekly training duration and sRPE-training load. Each player was considered in accordance with their age group team within the youth academy. The players that took part in all the team's training sessions that specific week and at least 75% of playing time of the competitive match were classified as starters. Non-starters were classified as players that performed all the team's training sessions but did not fulfil the match-related criteria. The cut-off of 75% was arbitrarily selected based off the different match durations across the youth academy age groups (e.g., 75% of an 80-minute match is 60 minutes). Each match is considered a separate event, indicating that a player could be both a starter and a non-starter for any specific match across the duration of the competitive seasons. The content of the training performed was not in any way influenced by the researchers. All training-related data were securely stored in bespoke software developed by the club.

Statistical Analysis

Hierarchical Linear mixed models were used to detect variation in mean weekly sRPE, total weekly duration, and total weekly sRPE-training load between age groups with the season as a fixed covariate effect. The differences between starters and non-starters were also investigated as a fixed effect, while individual players were considered a random effect with a diagonal covariance matrix. Each model's residuals were visually inspected for normality and estimated marginal means and 95% confidence intervals (CI) were calculated for each age group across all three dependent variables. Significant differences were further investigated by multiple pairwise comparisons using the model estimated marginal means, with Bonferroni correction applied. Cohen's effect size (*d)* was computed from the mixed model to assess the magnitude of differences between age groups. The thresholds utilized for the interpretation were: <0.20, *trivial*; 0.20–0.59, *small*; 0.60–1.19, *moderate*; 1.20–1.99, *large*; and ≥2.00, *very large* [135].

Week-to-week variation in sRPE-training load throughout the entire competitive season (i.e., including preseason and post-season phases) was also calculated. Coefficient of variation (CV) was calculated (i.e., the typical error expressed as a percentage of the mean score) and the smallest worthwhile change (SWC) was obtained by multiplying the between-subject standard deviation (SD) by 0.2 [136]. For this analysis, the CV and SWC data were grouped into four distinct periods of the season: Preseason (the training period before the first match of the competitive season), the first half of the season (period from the first competitive match of the season to the winter break), the second half of the season (period from the restart following the ~10-day winter break to the end of the competitive league season) and post-season (the period comprising play-offs following the league season). Analyses were conducted using SPSS version 22 (SPSS Inc, Chicago, IL, USA). All data presented are calculated as mean and standard deviation, or 95% confidence interval where shown. Statistical significance was set at p-value (*p*) < 0.05.

3.3 Results

Across the five competitive seasons, a total of 33,435 individual training observations were collected during the in-season period, with a range of 7,612 to 9,037 observations across the four age groups. Mixed models showed significant effects on playing status (i.e., starter vs. non-starter), age group and season average weekly sRPE, total weekly duration, and total weekly sRPE-training load. Models presented normally distributed residuals, estimated marginal means, and 95% CI are presented in Table 3.2.

Table 3.2. Estimated Means and 95% CI of the three load variables across the 4 age groups.

Age group	**sRPE (AU)**		**Duration (min)**		**sRPE-training load (AU)**	
	Starters	**Non-Starters**	**Starters**	**Non-Starters**	**Starters**	**Non-Starters**
U19	4.76 (4.72 – 4.80)	4.35 (4.32 – 4.38)	474 (474 – 475)	433 (432 – 433)	2427 (2406 – 2447)	2014 (1997 – 2031)
U17	4.96 (4.93 – 4.99)	4.52 (4.48 – 4.56)	498 (497 – 498)	456 (456 – 457)	2581 (2566 – 2596)	2170 (2149 – 2191)
U16	4.95 (4.92 – 4.98)	4.65 (4.62 – 4.68)	454 (454 – 455)	414 (414 – 415)	2343 (2326 – 2360)	2013 (1997 – 2030)
U15	4.22 (4.19 – 4.25)	3.90 (3.86 – 3.94)	453 (453 – 454)	414 (413 – 415)	1991 (1974 – 2008)	1668 (1647 – 1689)

Total weekly duration pairwise comparisons between the different age groups were all significant (all $p < 0.034$). Average weekly sRPE comparisons between age groups were all significant at $p < 0.001$ except for comparisons between the U17 and U16 age groups ($p = 1.00$). Total weekly sRPE-training load comparisons were all significantly different between age groups ($p < 0.001$), except between the U16 and U19 age groups ($p = 1.00$). Within age group differences recorded between starters and non-starters were significant for all three dependent variables. The differences within and between the different age group's weekly training load values are shown in Figure 3.1.

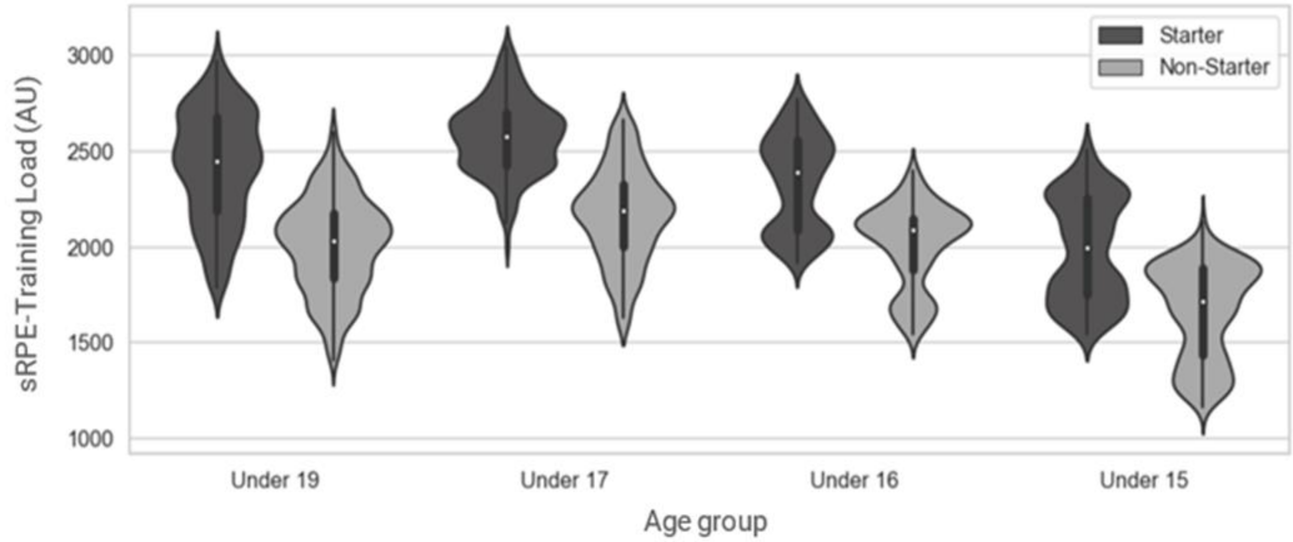


Figure 3.1. Violin plots of the total weekly sRPE-training load performed by starters and non-starters across the four age groups.

The magnitude of differences between the different age groups are presented alongside the estimated marginal means and 95% CI in Table 3. The week-to-week variation in training load and SWC across the different periods of the competitive season and four different age groups are summarized in Table 3.4.

Table 3.3. Pairwise comparisons and magnitude of differences between age groups (Cohen's *d*).

Load Variable	**Age group**	**Age group**	**Mean Difference**	**95% CI**		**Effect Size**
				Lower limit	**Upper limit**	
sRPE (AU)	U19	U17	-0.31	-0.42	-0.20	-0.33 (small)
		U16	-0.30	-0.41	-0.18	-0.31 (small)
		U15	0.45	0.33	0.58	0.45 (small)
	U17	U16	0.02	-0.08	0.11	0.01 (trivial)
		U15	0.76	0.66	0.87	0.81 (moderate)
	U16	U15	0.75	0.67	0.83	0.78 (moderate)
Duration (min)	U19	U17	-19	-29	-8	-0.25 (small)
		U16	+18	8	28	0.24 (small)
		U15	+27	18	37	0.36 (small)
	U17	U16	+36	27	46	0.51 (small)
		U15	+45	36	55	0.62 (moderate)
	U16	U15	+9	1	17	0.12 (trivial)
sRPE-Training Load (AU)	U19	U17	-178	-256	-100	-0.28 (small)
		U16	35	-44	114	0.05 (trivial)
		U15	457	377	536	0.69 (moderate)
	U17	U16	213	144	281	0.36 (small)
		U15	634	564	705	1.02 (moderate)
	U16	U15	421	361	481	0.67 (moderate)

The mean difference is significant at the 0.05 level for all comparisons except for: U17 vs U16 sRPE (*p* = 1.0) and U19 vs U16 sRPE-training load (*p* = 1.0). AU – arbitrary unit, min – minutes.

Table 3.4. Coefficient of Variation (CV) and Smallest Worthwhile Change (SWC) of weekly sRPE-training load across the four age groups.

Period of the competitive season			**Age group**							
Period	**Number of Weeks**	**Observations per week**	**U19**		**U17**		**U16**		**U15**	
	n	**n**	CV	SWC	CV	SWC	CV	SWC	CV	SWC
Preseason	4 – 8	13 – 96	3.6%	2.1%	6.2%	4.0%	3.9%	2.6%	4.6%	2.9%
1st Half of Season	14 – 17	26 – 53	2.4%	1.6%	3.6%	2.2%	2.4%	1.6%	3.0%	2.0%
2nd Half of Season	15 – 18	18 – 52	3.2%	2.2%	2.7%	1.8%	2.9%	1.9%	2.6%	1.7%
Post-Season	3 – 10	6 – 9	2.6%	1.7%	1.6%	1.1%	2.6%	1.7%	2.5%	1.7%

Number of weeks: range of weeks included in the period of the season, Observations per week: range of individual player observations per single week in the period.

4.4 Discussion

Differences between age groups, season period, and different seasons

The present study is the first known to provide a detailed description of the seasonal training load characteristics of elite youth soccer players across different age groups. The quantity of data assessed, and different levels of analysis provide important insights into the training load characteristics and periodization models applied within an elite Italian youth academy. The main findings show significant effects for age and playing status on sRPE, training duration, and total weekly sRPE-training load. Like previous studies [59, 137], we observed low levels of variation of load between the different phases of the season, with pre-season exhibiting the greatest changes in load between different training weeks.

The present results found a progressive increase in weekly training load from U15 to U17, with significant differences recorded between each age group. The increase observed in sRPE-training load was mirrored by the increase in weekly duration (training + match) across the three age groups. Notably, however, the increase in total weekly sRPE-training load and duration was not linear across the age groups, as the values for U19s were lower when compared to the U17s (*d* = -0.28, small).

This difference in U19 was due to lower levels of both sRPE and training duration, likely due to greater care in load management and preparation for the next competitive, more similar to an adult approach than the youth academy up to U17 [39]. The weekly sRPE-training load values reported in the present study are slightly lower than those previously reported in an Italian youth soccer population (2798 ± 322 AU in U17) [35], but greater than several English youth academies (U17 = 2091 AU [95] and U18 = 1041 AU (excluding a match) [96]), while markedly lower than those reported from an elite U16 team (2919 AU) [36]. These differences may be explained by different coaching philosophies or different training monitoring structures. While descriptive, the present results provide reference values from the largest cohort to date (across 5 competitive seasons) and identify the importance for practitioners to prepare youth players for the increase in sRPE load from U15 to U17.

We observed a moderate increase ($d = 0.78$) in mean perceived training intensity (sRPE) from U15 to U16 age groups (+0.7 AU), with this variable subsequently remaining similar between the 3 older age groups of the academy (trivial to small effect sizes). The in-season sRPE ratings observed in the current study are lower than those reported from a Brazilian youth academy (U15: 4.90 ± 0.30 and U19: 6.85 ± 0.34) [138]. The increase in perceived intensity between U15 and the older age groups is supported by previous from a Portuguese youth academy [64]. In that study, the authors suggested that U15 training was less physiologically demanding than the older age groups due to a greater emphasis being placed on technical aspects of the game [64]. Collectively, these findings indicate that the U15 age group elicits lower levels of perceived exertion and suggest that practitioners should focus on preparing these players for the increased intensity they will experience in the older age groups of the academy. While the small differences recorded in sRPE between U16 and U19 age groups indicate that player's perception of effort changes with age, it has previously been established that external loads performed increase as they progress through the academy system [15, 16, 20, 29].

The limited differences observed in sRPE values between the three older age groups ($d = 0.01 – 0.33$) highlight that the variations observed in sRPE-training load between these groups are likely attributable to changes in training duration. This finding is in agreement with a previous study on youth soccer [36], which also reported increases in sRPE-training load between age groups to be largely due to greater training duration. Similarly, a recent study assessing both professional rugby codes (union and league) also reported a large amount of the variability in sRPE-training load was explained by session duration (57-73%), with the intensity of a session (internal and external) explaining only 24-34% of the variance in sRPE-training load [139]. In this specific cohort the stability of sRPE levels may be due to similar training approaches and content being employed across the different age groups (U16 – U19), while the number of training session increases, contributing directly to increased training duration. When interpreted collectively, these findings show the importance of also evaluating (and controlling for) training intensity and duration separately. This finding has simple but important implications for practitioners who aim to control training load in youth football, as it shows that control of training session duration is an important driver.

Overall, the duration of training performed during an in-season training week is similar to previous studies from across different countries (e.g., Spain [92, 127] and the Netherlands [90]). The training duration recorded in the present study appears to be at the upper limit of the range performed by an English Premier League youth academy, which recorded ~400-420 min per week from the U15 to U18 age groups [15]. In addition, the stability reported in weekly training and match duration from U15 to U18 [15, 140] is like the small to moderate differences recorded between age groups in the present study (<36 min, $d < 0.51$). However, these findings are in contrast to a previous study that reported a progressive increase in weekly duration from U14 to U18 [36]. Collectively, these findings show that differences in weekly duration may be determined by the club's training schedule and diverse styles of training periodization adopted across clubs and countries.

The mixed-effects models revealed a significant effect of season on sRPE values, training duration, and sRPE-training load, indicating an important coach or group effect. This is particularly evident in the U15 and U16 age groups, where distinct differences in the distribution of sRPE-training load being recorded by both starters and non-starters can be observed in the violin plots. Changes in the weekly training plan within a season and between seasons may also influence the sRPE-training load recorded within a club. Similar variations have been observed in professional soccer, with head coaches influencing not only the proportion of training drills but also the physical load induced [131]. The importance of coach's input into the levels of training load and duration of individual sessions is supported by a survey of Premier League coaches and practitioners which highlighted that the content of training sessions was mostly determined by coaches [18]. However, it has been found that coaches' perceptions of the load being prescribed to their athletes and evaluation of the players recovery status may not always be aligned [141]. Differences between players developmental age [37] and the physical capacity of the specific group of players [142] may also account for differences in weekly loading strategies.

Difference between Starters vs. Non-Starters

The assessment of differences in training load characteristics between starters and non-starters is of particular interest to a youth academy to ascertain whether the players are receiving a sufficient physical stimulus to promote their physical development and maintain fitness in-season. Indeed, players who do not participate in an official match may also be exposed to lower levels of load, which places them at risk of losing match-specific fitness [110, 143]. We observed differences between starters and non-starters across all three variables, with non-starters reporting lower sRPE, duration, and sRPE-training load. From these results, the mean difference observed between starters and non-starters was 9-10% for training duration and 6-10% for sRPE, respectively. These differences contribute to considerable differences in total weekly sRPE-training load between starters and non-starters, ranging from 16–21% across the four age groups. This confirms previous observations of non-starters performing lower weekly loads across a range of different internal and external parameters [42, 127, 128].

The differences between starters and non-starters remained as the players progress through the youth academy (+400 AU, +40 min, and +0.35 AU respectively, for sRPE-training load, duration, and sRPE). However, the differences in weekly duration recorded between the two groups were less than the duration of a competitive match (i.e., a match duration of 70 min in U15, 80 min in U16, and 90 min in U17 and U19 age groups), indicating that some compensatory training was performed during the training week by the non-starters. It has previously been recommended that non-starters complete an additional training session to replicate at least part of the physical demands of a match and reduce the difference in load [42, 128]. Indeed, the dose of compensatory work performed by non-starters in this study increased with age, likely as an attempt to offset the differences in match exposure. These differences are similar to those observed in young professional non-starter players from a Spanish reserve team utilizing differential RPE scores (~ -500 AU for both respiratory and muscular RPE scores) [127]. However, different methods of identifying starters and non-starters make comparisons between studies difficult [110, 132]. Furthermore, in the present study, the criteria was based on players' completing all of the team's training sessions, not the levels of training load accumulated or individual differences across these sessions. Additional compensatory training completed by non-starters may play an important role in player preparation by protecting from reductions in chronic load, potentially protecting against increased injury risk and loss of fitness [130]. Indeed, any small deficits in training load between matches may accumulate into large differences when considered across an entire competitive season [110].

Variance in Training Load Variables

Given that changes in the levels of physical stimuli are considered important for promoting physical adaptations to training [144], it is important to assess the within-week variability of the load prescribed to athletes, particularly in the youth academy setting. The present findings showed that all age groups (U15 – U19) had the greatest variability in training during the preseason period, with the U17 age group exposed to the largest variances in load (6.2%). These observations are similar to reports on elite-level adult players [137], which showed little variability during in-season weekly training loads and minor decrements in variability as the season progressed. In general, the low levels of variability in load reported in the present study (< 3.6% in-season) and previous observations suggest that training weeks and the sRPE load accumulated tend to be reasonably stable within a standardized weekly plan. However, the week-to-week training variability observed in this study is lower than previously reported in elite adult Portuguese players (i.e., ~12-21% during 10 weeks including pre-season) [59]. This difference may be related to the comparison of a single season with a single coach as opposed to observations across a longer timeframe. It is also important to consider that differences in the variability reported between these studies may be due to changes in training structure (i.e., the number of weekly sessions) or the specific training philosophy applied within each organization.

The low threshold observed for SWC in-season training load in the present study (<2.2%) suggests that even small modifications to the training plan or contents can result in significant changes with respect to the previous weeks load. To date few studies have assessed or addressed questions relating to the variance of load being performed. Since there are many sources of variability in total weekly training load (including the training density, frequency, and volume), future studies might examine the contextual factors that influence the variability in training load applied in youth academies. In elite-level adult players, the training schedule (and load) during in-season has been related to the preparation for the next competitive fixture [40, 143]. This often includes modifying training and recovery activities to control player fatigue across the weekly micro-cycle, as opposed to focusing on players achieving their peak levels of physical performance [40, 143]. From a practical point of view, it is presently unknown if this loading pattern, characterized by limited variation in training loads, is best suited to youth athletes and their physical development.

Whilst the present study is the largest known report of training characteristics of youth soccer players, we acknowledge that all data were collected in one elite-level Italian academy and that the present observations may be influenced by cultural training differences specific to that organization. The differences recorded between age groups in this study indicate that this aspect merits further investigation, ideally using a multicentre approach including data from many elite youth soccer academies. Furthermore, in accordance with Impellizzeri's conceptual model for monitoring training load [22], the inclusion of the external load demands performed by the different age groups would help to further the evaluation, assessing internal and external loads together. A change in GPS units and athlete monitoring system utilized to archive the external load data during the 5-year timeframe employed compromised the continuity of the external load data being recorded in the present study. Future studies should also examine the micro-cycle structure and distribution of these loads across the different age groups or investigate the training load characteristics of elite youth soccer players physical performance levels. Furthering our knowledge on the age-related differences in levels of training load is essential for the planning of a long-term strategy for youth soccer players' physical development.

Practical Applications

Systematic monitoring of training load and its progression in elite youth soccer players provides key information that can be used as a reference to understand the performance levels elicited across an elite-level academy. The present results provide a novel insight into the quantity of weekly sRPE-training load elite youth soccer players are exposed to in each age group, with a progressive increase in these levels of load from U15 to U17. The observation that differences in sRPE-training load are more attributable to training duration than perceived intensity highlights that the control of session duration appears to play an important role when aiming to control load in the academy environment. The structured nature of in-season training results in little variance being recorded across the different age groups, however, there is a significant effect of playing status (starter vs non-starter).

CHAPTER FOUR

Study Three: How do young soccer players train? A 5-year analysis of the differences in weekly microcycle training load across an elite youth academy.

Chapter preface

This study aimed to build upon the previous chapter by providing a more detailed analysis of how in-season weekly training loads are distributed across a weekly microcycle. The main findings showed that competitive matches elicit the highest levels of daily training load during a weekly microcycle and that the periodization strategies employed are likely consequent to this. This work also highlights subtle differences between the different age groups that can increase practitioners' awareness of these aspects. A finding that can impact daily monitoring and facilitate training modulation is that differences in training load are more attributable to training duration than the perceived intensity.

4.1 Introduction

Controlling training load is widely considered to be essential for attaining desired training outcomes and preparing athletes to perform in both individual and team sports [27, 75, 145]. Evidence supporting relationships between training loads and performance [58, 60] and their association with risk of injury [146] has contributed to this monitoring process becoming increasingly important in professional soccer teams and elite youth academies. Accurate monitoring of an individual soccer player's daily training load is essential for its effective manipulation, attaining the specific goals of each training session [15, 39], and improving physical adaptations [40, 75].

During the in-season, the training plan design – or training periodisation – is aimed to optimize the players' performance levels and is usually structured according to the time frame of the intervention (macro-, meso- or micro-cycles) [145, 147]. The strategies applied within these distinct periods aim to balance the technical-tactical elements of training with the physiological stimulus required to maintain or increase individual players physiological capacities [18]. Micro-cycles represent the building blocks of a training plan and encompass diverse elements (e.g., loading, recovery, skill development, etc.) that are key to the management of training load [39, 145] and likely to impact players performance levels [145]. Indeed, factors relating to the volume and intensity of training need to be carefully controlled between matches if athletes are to receive a sufficient training stimulus to maintain their physical qualities and sufficiently recover before future matches [148]. This aspect becomes increasingly important when repeated cycles of competition make it difficult to provide an adequate training dose to develop physical capacities [149] and influence injury risk [150]. This is a critical component for training in elite-level youth academies, where one of the main objectives is to produce players that are physically prepared for the demands of the professional game. Gaining a greater understanding of the microcycle structure can aid the planning phase and help to ensure that youth players are best prepared for the age-related training demands.

The manipulation of training load variables (i.e., duration, intensity, frequency, distribution, and nature of training) can directly influence the physical stimulus that players are exposed to during a soccer-specific training plan [20, 130]. At present, the quantity and distribution of training loads performed during weekly micro-cycles have been described in elite and sub-elite level adult soccer players from across different European countries (e.g., England, Spain, Portugal, The Netherlands; age range: 20 – 27 y) [39-42, 127-129, 151]. These studies mainly assessed external load and highlighted substantial differences in the periodization of load across a weekly micro-cycle, modulating the volume and intensity of load performed across the different sessions [39-42, 127-129, 151]. There appears to be a distinct “loading phase” before a marked reduction in load (tapering phase) preceding the next competitive match [39, 40, 42, 151]. Indeed, another key aspect to consider when evaluating the load prescribed within a training plan is the variability of the physical stimulus, widely considered to be one of the primary drivers of training adaptation [119, 145, 152]. This is of relevance for youth soccer players, who have not yet reached their full physical development [130], where there is an emphasis on developing their physical capacities as they progress through the academy. Furthermore, the loading strategies applied during in-season training of elite adult soccer players [39, 40, 42, 129] may not be appropriate for younger athletes. Gaining a greater understanding of the loading strategies applied in micro-cycles, and their variability can help inform periodization in this specific population.

To date, few studies have assessed the training characteristics and training loads experienced by elite youth soccer players [15, 29, 30] during in-season micro-cycles. These studies have described the weekly training load profile and quantity of load accrued on the different days of a weekly micro-cycle, documenting subtle differences in the loading strategies applied across different age groups in elite English and Portuguese youth soccer players [29, 30]. Reduced variability in training load between- and within-weekly microcycles have also been reported in young soccer players, with slight differences recorded according to playing position [149]. However, these aspects have yet to be fully examined as studies have reported cohorts with limited sample size, over relatively short periods (e.g., from two to nine weeks, up to one competitive season) [15, 29, 30], and are recorded from a single club and/or coach. Further insights into the training loads experienced within a weekly microcycle, and how it is influenced by player age, can help to inform decisions relating to the training plan in these specific age groups.

Studies that describe the age-related changes in training load are required to understand best practice approaches and inform the development of elite youth players. To date, few studies have specifically assess this aspect across different age categories. Gaining a greater understanding regarding the periodization of load across a weekly micro-cycle and difference between age groups, can help to inform the training plan. Therefore, this study aimed to describe the distribution of training load variables (sRPE, duration, and sRPE-training load) across a weekly microcycle and the differences in the management of these load variables across different age groups of an elite youth academy.

4.2 Methods

Experimental Approach to the Problem

Descriptive analyses were conducted on in-season training and match data collected across five seasons (2014-15 to 2018-19) via a player monitoring program of an elite youth soccer academy. Recording data from a new team for each age group each season ensure 5 years of data across all age categories of the academy system. Mixed models were utilized to conduct a cross-sectional analysis of sRPE, duration, and sRPE-training load recorded by four different age groups (U15, U16, U17, and U19). The distribution of these variables across weekly training microcycles including 4 training days before a match was assessed. In the current study only full training weeks from the in-season period, including one competitive fixture, were considered for the analysis.

Subjects

Elite male youth soccer players from the same soccer academy participated in this study. For the analysis, players were grouped according to their age group (U15 - U19), with a new squad of players monitored in each age group, each season. The player's anthropometric measures are presented in Table 4.1. Fifty-nine players recorded repeated measures as they progressed across the different age groups of the youth academy. Written consent was obtained from each subject and their legal guardian before the commencement of the study. The study was approved by the University Research Ethics Committee (UTS HREC ETH19-4420). To be eligible for the present study the players had to complete at least 1 complete in-season training week and competitive match.

Table 4.1. Anthropometric measurements collected from players of the four age categories across the 5 competitive seasons evaluated (mean ± SD).

	Under 15	**Under 16**	**Under 17**	**Under 19**
n	107	108	104	137
Age (y)	14.4 ± 0.3	15.4 ± 0.3	16.4 ± 0.4	17.9 ± 0.7
Height (cm)	172.9 ± 6.6	177.0 ± 6.2	179.0 ± 5.8	179.5 ± 12.4
Body mass (kg)	59.3 ± 7.2	65.5 ± 6.4	69.4 ± 6.2	74.8 ± 11.3

Procedures

Each player's internal load responses to training and matches were quantified via session-RPE (sRPE) method using the CR10 scale [79, 134]. At the start of each season, all players participated in an education session designed to familiarize them with this method and the correct use of the Borg Scale [134]. A validated Italian translation of the Borg Scale [25] was utilized to facilitate this monitoring process across all age groups and seasons. Players sRPE score was systematically collected by the teams' sports scientist ~30 min following the end of every session, conducted on a one-to-one basis by looking at the scale and verbal anchors (e.g., and RPE of 2 is "leggero/light", 3 is "moderato/moderate" and 5 is "pesante/hard". The players were systematically asked "what was their perception of effort for the training session (or match) they have just completed". This process ensured a continued verification of players understanding of the scale and the perception of effort they recorded. The duration of each training session (minutes) refers to the time elapsed from the initiation of warm-up to the completion of the last drill. On match days the duration refers to the sum of warm-up (~25 min) and the length of the competitive game. The sRPE-training load for each session was subsequently calculated by multiplying the player's sRPE by the duration of the session [79]. All training-related data was securely stored in a bespoke in-house database developed by the club.

To standardize the microcycle analysis between the five different competitive seasons and different age groups (i.e., different rest days or modified training schedules) we determined the weekly microcycle to include four training days before a match. This selection was made to normalize the micro-cycles from additional sources of variability (e.g., influenced by travel requirements). The mean weekly microcycle distribution (day-to-day variance) was assessed by evaluating the different training days in relation to the next competitive fixture (e.g., three days before a match is calculated as Match Day (MD) minus 3 (MD-3)). Data included for the analysis required the players to have completed all team training sessions that specific week and at least 75% of the competitive match. The number of weeks included in the analysis ranged from 56 to 98, with the two older age groups (n = 73 and 56 for U17 and U19 respectively) recording fewer "standard" weeks due to more congested fixtures and flexibility in their training schedule.

The tactical objective of each session guided the selection of drills and pitch dimensions applied by coaches. The content of the training sessions consisted of technical and tactical drills, including passing and control drills, small-sided games, ball possession drills, and training matches. In addition to pitch-based drills, the players also performed one session per week dedicated specifically to gym-based exercises (~40 min) comprising body-weight functional exercises and exercises utilizing isoinertial machines. Details relating to the program of a standard training week are shown in table 4.2.

Table 4.2. Overview of a typical training week for the four age groups of the youth academy.

	MD-x	**Under 15**	**Under 16**	**Under 17**	**Under 19**
MON	MD-6	Rest	Rest	Rest	Rest
TUE *	MD-5	TT, RD	TT, RD	TT, RD	TT, RD
WED	MD-4	RT, TT	RT, TT	RT, TT	RT, TT
THU	MD-3	TT	TT	TT	TT
FRI	MD-2	TT	TT	TT	TT
SAT	MD-1	Rest	Rest	TT	TT
SUN	MD	Match	Match	Match	Match

MD-x: number of days prior to the next competitive match (MD), Rest: day off / with no official training session programmed, TT: technical & tactical training drills (including numerous diverse methods, e.g., technical exercises, small-sided games, training matches etc.), RD: aerobic endurance running drills, RT: resistance training performed in the gym. *, not assessed in the present study.

Statistical Analysis

Hierarchical linear mixed models were used to detect differences in sRPE, session duration, and sRPE-training load across the different training days of a weekly training microcycle and between the four different age groups. Individual players were included as a random effect with season and age group considered as fixed covariates because repeated measures were recorded for each player across the different micro-cycles and competitive seasons. Estimated marginal means and 95% CI were calculated for each Match Day of the microcycle for all three outcome variables with a Bonferroni correction applied. To better interpret the variation between the different age groups we computed Cohen's *d* effect size. The threshold values utilized for the interpretation of Cohen's *d* were as follows: <0.20, *trivial*; 0.20–0.59, *small*; 0.60–1.19, *moderate*; 1.20–1.99, *large*; >2.00, *very large* [135]. Statistical significance was set at $p < 0.05$. All analyses were conducted using SPSS version 22 (SPSS Inc, Chicago, IL, USA).

4.3 Results

The in-season training data of 230 unique players were recorded during the five competitive seasons analysed, for a total of 5,557 individual training observations across the four age groups. Details relating to the differences between age groups within each training day of the microcycle are presented in Table 4.3. Comparisons of sRPE, duration, and sRPE-training load of each age group, stratified per MD-*x*, are presented in Figure 4.1. The magnitude of differences between age groups from pairwise comparisons are presented in Table 4.4. U15 recorded lower levels of sRPE on MD-4 and MD-3 compared to the older age groups (d = 0.43 – 0.72). The day before a match (MD-1) U16 recorded the highest sRPE, with small differences compared to U15 and U17 (d = 0.50 and 0.38, respectively), while moderate for U19 (d = 0.70). Moderate increases were found in levels of sRPE between U15 and U16 (d = 0.91) on MD. Only small increases in sRPE were observed on MD from U16 to U17 (d = 0.31) before a plateau between U17 and U19 (trivial, d = -0.06).

On MD-4 training duration was significantly lower for U19 than in the other age groups (d < -1.10). A small difference in duration remains between U19 and the younger age groups in MD-3 (d = -0.43 – -0.49). Only U15 recorded small differences in duration compared to the older age groups on MD-2, while U17 recorded lower duration on MD-1 (d = -0.34 – -0.46). Small increases in match duration resulted in a moderate difference between U15 and U19 (d = 1.07) and U16 and U19 (d = 0.73), respectively.

Moderate differences in sRPE-training load were observed on MD-4, with U19 levels lower than U16 and U17 (d = -0.65 and d = -0.94, respectively). On MD-3 U17 recorded the highest sRPE-training load, with small differences compared to the other age groups. Only U15 reported small differences in sRPE-training load compared to the older age groups on MD-2, while U19 was found to have lower levels compared to U15 and U16 on MD-1 (d = -0.51 – -0.62). A gradual increase was observed in sRPE-training load on MD across the different age groups, with moderate differences observed between U15 and U17 (d = 1.16), increasingly to a large difference between U15 and U19 d = 1.38).

Table 4.3. Mean difference (± 95% CI) of sRPE, duration, and training load between the four age groups across match days.

Variable	Age Group		MD-4	MD-3	MD-2	MD-1	MD
sRPE (AU)	U19	U17	0.36* (0.08 – 0.63)	-0.01 (-0.29 – 0.27)	-0.05 (-0.28 – 0.18)	-0.37* (-0.06 – -0.12)	-0.10 (-0.41 – 0.20)
		U16	0.40* (0.13 – 0.67)	0.34* (0.07 – 0.60)	-0.09 (-0.31 – 0.13)	-0.84* (-1.17 – -0.51)	0.44* (0.14 – 0.74)
		U15	1.11* (0.84 – 1.37)	0.97* (0.71 – 1.23)	0.16 (-0.06 – 0.38)	-0.35* (-0.69 – -0.00)	2.17* (1.87 – 2.48)
	U17	U16	0.04 (-0.16 – 0.25)	0.34* (0.12 – 0.57)	-0.05 (-0.24 – 0.15)	-0.47* (-0.81 – -0.12)	0.54* (0.30 – 0.79)
		U15	0.75* (0.55 – 0.95)	0.98* (0.76 – 1.20)	0.21* (0.02 – 0.40)	0.03 (-0.32 – 0.37)	2.28* (2.02 – 2.56)
	U16	U15	0.71* (0.53 – 0.88)	0.63* (0.44 – 0.82)	0.25* (0.09 – 0.42)	0.50* (0.11 – 0.88)	1.73* (1.52 – 1.94)
Duration (min)	U19	U17	-44* (-50 – -38)	-14* (-18 – -8)	0 (-3 – 2)	6 * (2 – 9)	7* (4 – 10)
		U16	-34* (-40 – -28)	-14* (-19 – -9)	2 (-1 – 5)	2 (-6 – 3)	14* (11 – 17)
		U15	-37* (-43 – -32)	-13* (-18 – -8)	5* (3 – 8)	0 (-5 – 5)	21 * (18 – 25)
	U17	U16	10* (5 – 15)	-1 (-5 – 4)	2 (-0 – 5)	-7* (-12 – -3)	7* (4 – 9)
		U15	6* (2 – 12)	1 (-3 – 5)	6* (3 – 8)	-6* (-11 – -1)	14* (12 – 17)
	U16	U15	-4 (-8 – 1)	2 (-2 – 5)	3* (1 – 6)	1 (-4 – 7)	8* (6 – 10)
sRPE-Training Load (AU)	U19	U17	-185* (-221 – -149)	-75* (-107 – -42)	1 (-23 – 24)	-14 (-34 – 7)	62* (22 – 101)
		U16	-128* (-163 – -93)	-39* (-71 – -8)	3 (-19 – 25)	-55* (-82 – -28)	161 * (121 – 201)
		U15	-48* (-82 – -13)	31* (1 – 62)	42* (21 – 63)	-46* (-75 – -16)	361* (320 – 402)
	U17	U16	57* (27 – 87)	35* (8 – 62)	2 (-18 – 22)	-42* (-71 – -12)	100* (68 – 131)
		U15	138* (108 – 167)	106* (79 – 133)	42* (22 – 61)	-32* (-63 – -1)	299* (267 – 332)
	U16	U15	81* (55 – 107)	71* (47 – 94)	39* (22 – 56)	10 (-25 – 44)	200* (173 – 227)

*, sig. effects at $p < 0.05$. AU – arbitrary units, min – minutes. MD-4: four days prior to the next match, MD-3: three days prior to the next match, MD-2: two days prior to the next match, MD-1: one day prior to the next match, MD: Match Day.

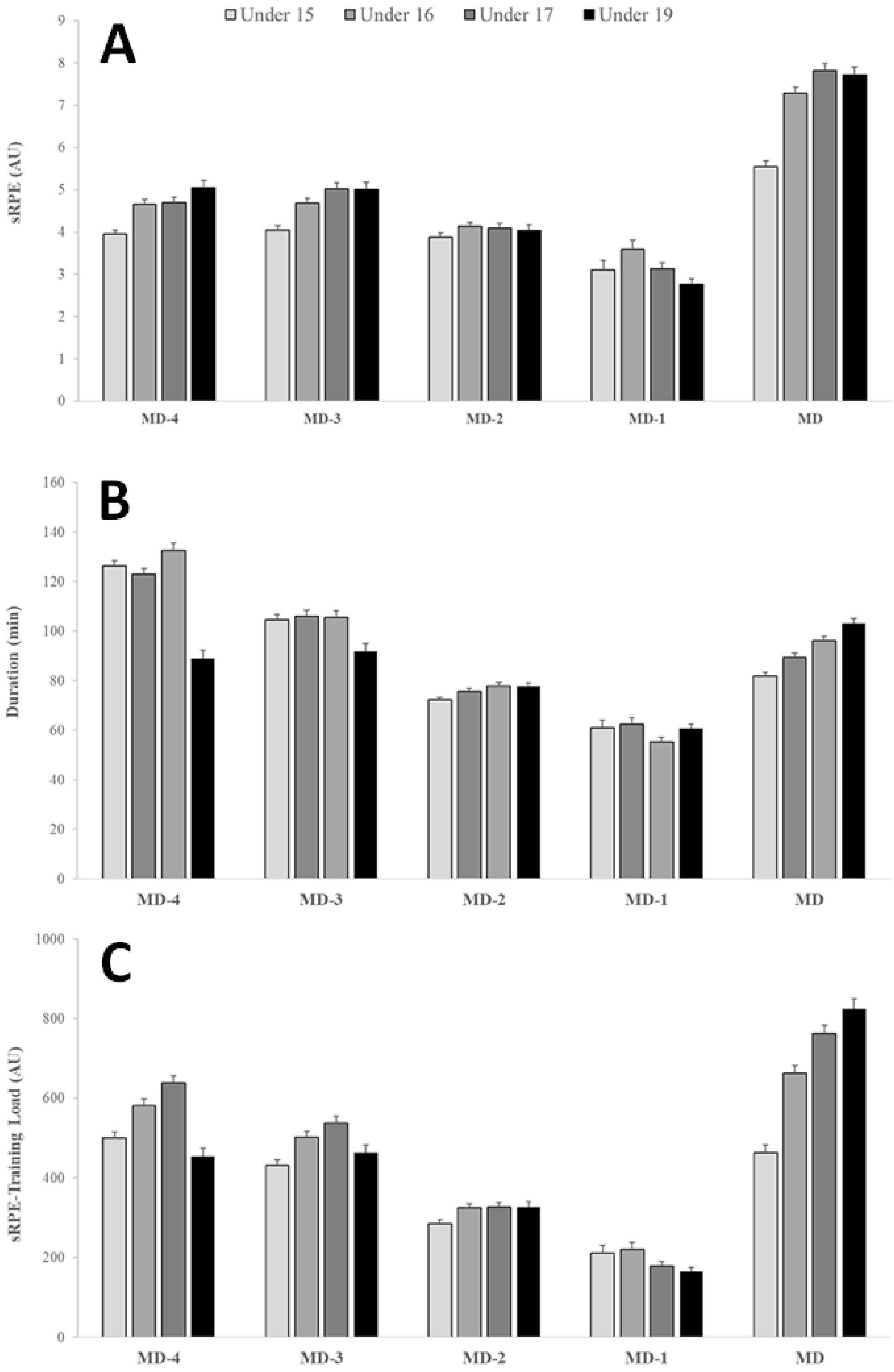


Figure 4.1. Mean (± 95% CI) values from across 5 competitive seasons for Match Day and Age Group for A) session RPE (sRPE), B) training duration, and C) sRPE-training load.

sRPE – rating of perceived exertion, AU – arbitrary unit, min – minutes. MD-4: four days before the next match, MD-3: three days before the next match, MD-2: two days before the next match, MD-1: one day before the next match, MD: Match Day.

Table 4.4. Magnitude of differences between age groups (Cohen's d) across the weekly microcycle.

Match Day	Age group	Age group	RPE (AU) Effect Size	Duration (min) Effect Size	Training Load (AU) Effect Size
MD-4	U19	U17	0.24 (small)	-1.42 (large)	-0.94 (moderate)
		U16	0.27 (small)	-1.10 (moderate)	-0.65 (moderate)
		U15	0.72 (moderate)	-1.19 (moderate)	-0.23 (small)
	U17	U16	0.03 (trivial)	0.32 (small)	0.29 (small)
		U15	0.52 (small)	0.20 (small)	0.67 (moderate)
	U16	U15	0.49 (small)	-0.11 (trivial)	0.39 (small)
MD-3	U19	U17	-0.01 (trivial)	-0.48 (small)	-0.42 (small)
		U16	0.23 (small)	-0.49 (small)	-0.22 (small)
		U15	0.65 (moderate)	-0.43 (small)	0.17 (trivial)
	U17	U16	0.23 (small)	-0.02 (trivial)	0.20 (small)
		U15	0.66 (moderate)	0.03 (trivial)	0.58 (small)
	U16	U15	0.43 (small)	0.05 (trivial)	0.38 (small)
MD-2	U19	U17	0.04 (trivial)	-0.02 (trivial)	0.01 (trivial)
		U16	0.07 (trivial)	0.14 (trivial)	0.02 (trivial)
		U15	0.12 (trivial)	0.37 (small)	0.33 (small)
	U17	U16	0.03 (trivial)	0.16 (trivial)	0.02 (trivial)
		U15	0.15 (trivial)	0.39 (small)	0.32 (small)
	U16	U15	0.19 (trivial)	0.23 (small)	0.30 (small)
MD-1	U19	U17	-0.29 (small)	0.34 (small)	-0.15 (trivial)
		U16	-0.70 (moderate)	-0.12 (trivial)	-0.62 (moderate)
		U15	0.29 (small)	-0.03 (trivial)	-0.51 (small)
	U17	U16	0.38 (small)	-0.46 (small)	-0.44 (small)
		U15	0.02 (trivial)	-0.38 (small)	-0.34 (small)
	U16	U15	0.50 (small)	0.10 (trivial)	0.11 (trivial)
MD	U19	U17	-0.06 (trivial)	0.40 (small)	0.26 (small)
		U16	0.25 (small)	0.75 (moderate)	0.66 (moderate)
		U15	1.13 (moderate)	1.07 (moderate)	1.38 (large)
	U17	U16	0.31 (small)	0.37 (small)	0.42 (small)
		U15	1.20 (large)	0.73 (moderate)	1.16 (moderate)
	U16	U15	0.91 (moderate)	0.38 (small)	0.77 (moderate)

RPE – rating of perceived exertion, AU – arbitrary units, min – minutes. MD-4: four days before the next match, MD-3: three days before the next match, MD-2: two days before the next match, MD-1: one day before the next match, MD: Match Day.

4.4 Discussion

The present study provides a detailed analysis of the distribution of sRPE, training duration, and sRPE training load recorded by elite youth soccer players during in-season weekly micro-cycles. In all age groups, the most demanding day of the weekly microcycle was match day, with increased duration and sRPE compared to in-week training sessions. The main findings were significant differences in the daily training demands of a weekly micro-cycle, with notable differences in U15 and U19 compared to the two central age groups of the youth academy (i.e., U16–U17). These differences were mainly observed in the mid-week training sessions (MD-4 and MD-3) and likely related to the management of the stimulus prescribed to the players; with U15 recording lower sRPE and U19 lower duration. This may be explained, in part, by the large differences in MD training loads and the increased frequency of matches played by U19 compared to U15.

Similar to previous studies on Italian youth football players, the load incurred during a match in the present study accounted for ~25% of the week's total sRPE-training load [22]. Following national youth academy regulations, we observed match duration to increase systematically across the different age groups. However, the increase in duration was not mirrored by an increase in sRPE, where a plateau in perceived match intensity is observed from U16 to U19 age groups (7.5 – 8.1 AU) after a moderate increase from 5.7 AU in U15. These sRPE scores observed in the present study are slightly higher than those previously reported from semi-professional Italian youth soccer players [78] but lower than those reported from an elite English youth academy (8.4 – 8.5 sRPE (AU) for U14, U16, and U18, respectively), where no differences were recorded between age groups [30]. Determining the reasons for any differences in perceived match intensity is difficult, but factors such as the level of competition, game tactics/styles between different teams, and/or differences between the various cohorts may play a role.

Current results align with previous observations from professional soccer players which have highlighted the most demanding training sessions are conducted in the middle of the training week [42, 128]. In the present study, the sRPE-training load was found to be greatest on MD-4 for U15 – U17, before a progressive decrease to the next MD. This is however in contrast with other reports on elite adult players, where a small to moderate increase in sRPE-training load was observed between MD-4 and MD-3 [39, 127]. The general observation of increased sRPE-training load in these sessions shows that the greatest internal training stimulus – or “loading phase” – is completed three to four days before MD. This approach allows for a sufficient physical stimulus to be applied to prevent detraining but also adequate time for any transient fatigue to substantially reduce before the next match [145].

Whilst there was a generally consistent pattern across all age groups, there were also some subtle differences between the age groups. Specifically, the sRPE-training load was lower during MD-4 and MD-3 in the youngest age group (U15), with the lower loads recorded attributed to lower sRPE values as the duration of the sessions is stable compared to U16 and U17. This may be due to a greater emphasis being placed on teaching the youngest age group of the youth academy important technical and tactical skills [64]. This phenomenon has previously been documented in elite youth Portuguese soccer players [64] and resulted in less physiologically demanding training sessions compared to U17 and U19 age groups. Indeed, an increased emphasis on the coaching of fundamental principles often requires more stoppages during training to explain game situations and less focus on the internal load elicited.

For the present study, we analysed a microcycle period including 4 training sessions before a match to maximise the number of observations across all four age groups, as the U19 age group tends to have much fewer 5-day microcycles than their younger counterparts. Therefore, it must be acknowledged that the internal training load recorded in these sessions could be influenced by the extent of recovery from the previous match [148] and the quantity of load performed in the MD-5 session. This appears to be more relevant when evaluating the periodization strategy applied in U19, as it was observed to include lower training duration and overall sRPE-training loads on MD-4 compared to the younger age groups. In general, the U19 age groups sRPE-training load was more evenly distributed across the micro-cycle, with less variability in training duration. A likely explanation for this subtle change in microcycle loading in U19 is the increased match load induced (in both sRPE and duration) and the increased frequency of match play in this age category [39]. Indeed, the sRPE training load recorded in U19s is similar to reports from professional players [39, 40, 137] and more closely reflects the organisation of an elite professional team; aiding the management of fatigue induced by the previous match (greater for U19 than U15) and allowing for the preparation of the next competitive fixture. This is likely due to the deliberate approach of youth academies to best prepare players for the professional game, increasing the similarity with first team practices as the players progress through the academy.

All age groups demonstrated a reduction in sRPE training load in the two days before MD, a weekly micro-taper, as reported elsewhere [151]. Whilst a pre-match taper is common, there have been different approaches reported. For example, a progressive decrease across the training week [39, 128], or a marked reduction in volume and intensity only on the day before a match (MD-1) [40, 42, 149]. In the present study, the reduction of sRPE-training load from MD-3 to MD-2 is greater than previously reported in elite English Premier League soccer players (~70–90 AU) [39], with slight differences observed between the different age groups. Interestingly, the progressive decrease observed in sRPE-training load across the weekly microcycle follows a similar pattern to the duration of the training, generally reduced by half for U15 - U17 age groups (~120 to 60 min), highlighting the importance of managing this specific variable for achieving pre-planned loading goals.

The evaluation of training duration and intensity separately provide more insight into the nature of the training periodization. In the present study sRPE values recorded were found to be similar between the four age groups and stable at a moderate to high intensity in the mid-week training sessions (RPE between 3.88 – 5.02 AU for MD-4 – MD-2). This observation agrees with previous reports assessing levels of sRPE recorded in both youth (39) and elite level soccer players (23), even though small differences have been reported between different playing positions across the weekly microcycle (23).

The short taper period completed during an in-season weekly microcycle allows for the reduction of training stress and improves physical readiness, which has been shown to promote both recovery and performance [145]. In the present study, a reduction in sRPE was recorded only on MD-1, showing the pre-match taper to consist of both a reduction in volume and intensity. However, studies conducted on elite-level football teams have previously recorded no change in training duration during MD-1 [137, 153], suggesting that changes in sRPE-training load were due to a reduction in perceived exertion during these sessions. When interpreted collectively, reports highlight that a short taper period is common in soccer, however consistent approaches are not apparent. The periodization of load applied during the taper may be related to the philosophies of specific coaches or related to other factors related to the management of physical adaptations and performance [147, 154]. Furthermore, it must be considered that the difficulty level of the next competitive match may also influence the external loads prescribed during a competitive microcycle and on the day before a match [155].

Another interesting observation across the four age groups relates to the stability of the levels of training load and volume observed during the five-year observation period. Notably, this stability remained despite changes in coaching staff and players across the study period. This finding highlights the use of a common general structure for the programming of in-season training micro-cycles in elite youth soccer. This limited variation in weekly micro-cycles also contributes directly to the small fluctuations across longer periods of the season [39, 40]. However, in accordance with Impellizzeri's conceptual framework [22], the evaluation of external load metrics is required to fully comprehend the load being performed by the youth players across a weekly micro-cycle, as the stability observed in internal load may not represent the external load prescribed. The 5-year timeframe utilized in the present study did not allow for the inclusion of external load measures as a change in GPS units and athlete monitoring system utilized to archive the data compromised the continuity of the data being recorded. This extended period of observation, comprising different head coaches and staff, also limited the possibility of including more specific details relating to the use of different proportions of drills (e.g., number and which drills were selected on different days across the weekly microcycle) and weight of the training load accrued by specific training drills. Having a greater quality of information available and understanding of the relationships with drills, their periodization and load incurred can facilitate an integrated collaborative prescription process. Indeed, a limitation of the present study is that all data were collected from the same elite-level academy and greater details regarding the differences between age groups external load (i.e., GPS data) across the training week are also warranted. Furthermore, when interpreting the training load data, the assessment of each player's variations in load is recommended.

The present study provides a detailed analysis of the distribution of sRPE, training duration, and the sRPE-training load of elite youth soccer players assessed across a long timeframe and with a greater number of subjects than previous reports. Differences in sRPE and duration were observed between the different training sessions within in-season training micro-cycles and age groups (mainly U15 and U19). The magnitude of reduction in sRPE-training load during a weekly microcycle appears to be attributable to the reduction in training duration. This insight can aid practitioners working in elite youth soccer academies to guide decisions relating to load management across distinct age groups and help to influence the players subsequent performance [156]. A sub-analysis assessing differences between playing positions may also help to further insights into the internal load requests between different positional groups.

Practical applications

The application of an evidence-informed approach to training design can aid the planning of progressive training programs that facilitate elite youth players transition between the different age groups of an elite academy. The detailed description of the training characteristics of a weekly microcycle provided in this investigation can assist practitioners and coaches in better understanding and therefore preparing players for training and competition. The stability of sRPE values during the three central sessions of a weekly microcycle means that manipulating training duration appears to be one of the key moderators in this process, with changes aimed at fine-tuning the plan for recovery between matches (e.g., U19) and optimizing performance in the next competitive fixture. This management may be due to the elevated stimulus recorded during matches (sRPE and sRPE-training load in particular), representing an important physical burden across all four age groups. Future studies should also examine the relationship between the internal and external load recorded across the different age groups.

CHAPTER FIVE

Study Four: Rating of perceived exertion in elite youth soccer players: what variables contribute the most?

Chapter preface

This study aimed to examine which internal and external training load variables contribute the most to elite youth soccer players levels of sRPE. Examining these relationships is important for the training programming phase and attaining the desired intensity of internal load. Identifying the load metrics that exert the greatest influence can help practitioners to understand which variables to modulate. Including variables from different constructs of load supports the importance of both internal and external load and the role these can play on influencing youth soccer players perceived exertion. Furthermore, determining the consistency of these relationships across the different age groups of an academy aid the implementation of an academy wide approach.

5.1 Introduction

Athlete monitoring systems are commonly used to assess and control the training dose so that the athlete's adaptive responses can be optimised [20]. In football, the increased availability of wearable microtechnology and other athlete monitoring tools allows for the regular and systematic monitoring of individual player's training load and their responses to that load [18, 130]. This allows coaches and applied sports scientists to collect a wide array of information (and different metrics) about the stressors experienced during diverse training activities and matches and this informs the selection of future training activities [26]. From the practitioner's perspective, monitoring measures must provide meaningful information to guide decisions about future training (i.e., the selection of training activities and quantity of load to perform) [28, 61, 157, 158]. To date, the selection of load variables utilized in daily monitoring programs and the perceived importance of each variable is often based on the training philosophy applied within the specific club [26, 159].

A conceptual framework, now widely applied across numerous sports, describes the training load completed by athletes as either the external or internal load [22, 75]. Within this framework, the external load is defined as the quantity and intensity of work performed, independent of individual characteristics or fitness levels, and internal load refers to the psycho-physiological stress-induced to perform the external work. Wearable microtechnology devices consisting of integrated GPS and microsensors are now fundamental for the quantification of external loads performed during soccer training and matches [8, 43]. These devices provide information relating to the volume, intensity, and frequency (i.e., TD, speed zones, number of sprints and ACC events, etc.) [26, 28] performed by each player. Internal training load has been identified as the mediator of athlete's adaptations to a training dose [133, 160] and can be assessed using several different variables [22]. A method used to assess the internal load is the sRPE method, calculated as the product of the RPE and its duration [79]. This method, administered via a psychophysical scale, has previously been validated for team sports, including soccer [79, 160] and helps to quantify and monitor each players individual perception of exercise intensity. This construct can also help practitioners to inquire about the nature of the effort perceived, differentiating between central (i.e., cardiorespiratory, breathing, or chest) and peripheral (local or muscular) [161]. Practitioners regularly employ this method in their training monitoring programs as it is a simple, inexpensive, and non-invasive method that can be applied at any level and, importantly, across all training activities [159, 162].

Recently, it has been suggested that valuable insights relating to the nature of training can be obtained by examining the relationships between the external and internal loads performed during soccer training [163-166]. In team sports it has been reported that sRPE has a stronger relationship with external load compared to HR-based TRIMP measures [163, 167]; with a strong association with the total distance being reported in both semi-professional [168] and professional soccer players [163, 169]. Large correlations have also been observed between sRPE and ACC-derived PlayerLoad [169], as well as distances travelled at high-speed running speeds (HSR) and other intense actions (i.e., number of ACC and impacts) [164]. These insights indicate that both the volume and intensity of training load performed influence soccer players levels of sRPE. To date, few studies have assessed these relationships in youth soccer or established the best contributors to sRPE in this specific population. One study conducted on Polish youth soccer players found that a combination of external load variables was required to predict sRPE (e.g., PlayerLoad, HSR, and AD) [170]. However, this study did not include any other internal load measures (i.e., heart rate measures) and only evaluated one specific age group (U19) [170]. The evolution or continuity of these relationships across different age groups of a youth academy has yet to be determined. Assessing the strength and direction of these relationships with other internal and external measures during training and match activities in youth soccer can assist with the development of specific periodization strategies for both the team and individual athletes [160].

Improving our understanding of the impacts of different elements of training load upon sRPE can inform the design of training programs and the selection of training activities. Accordingly, understanding the relationships between specific measures of load and sRPE during training and competition across the different age groups of an entire youth academy can also greatly aid practitioners to understand (and predict) the training stimuli provided [27, 163, 165]. Indeed, establishing these relationships can support the use of a “session builder” planning tool (i.e., a tool that prospectively predicts future training loads, based on the training plan) to attain positive training outcomes and the design of training interventions [171]. The session builder tool is based off the archive of all drills performed and catalogued in the database for each age group and individual competitive season, providing an estimate of the load each drill will elicit, according to its duration in time. When this information is applied in the planning phase, it may be used to guide the selection of training activities, and their periodization, to support long-term player development through improved training load control [172, 173]. Therefore, this study aimed to determine which internal and external training load variables contribute the most toward the sRPE of elite youth soccer players.

An additional objective was to examine the consistency of the relationships between sRPE and load across the four different age groups of the youth academy.

5.2 Methods

A longitudinal observational study design was adopted to evaluate which internal and external load variables contribute most to sRPE in elite youth soccer players. The data relating to every training session and match performed was collected over 47 weeks (comprising both pre-season and in-season phases) for two competitive seasons (2017-18 and 2018-19). The consistency of outcomes was assessed across four different age groups of an elite-level Italian academy.

Participants

One hundred and forty-five elite youth soccer players, belonging to the U15 to U19 age groups of the same elite level soccer academy, participated in this study. To be eligible for the present study the players had to complete all of a single training session and/or match and be present within the youth academy squad for the two competitive seasons assessed. The players anthropometric measures are presented in Table 1. The dataset included 31 central defenders, 47 central midfielders, 36 wingers, and 31 attackers from across the four different age groups. Written informed consent was obtained from each player and their legal guardian before the commencement of each competitive season. The study was approved by the University Research Ethics Committee (UTS HREC ETH19-4420).

Table 5.1. Player's anthropometric measurements across 2 competitive seasons (mean ± SD).

	Under 15	**Under 16**	**Under 17**	**Under 19**
n	50	33	29	33
Age (y)	14.5 ± 0.2	15.4 ± 0.3	16.4 ± 0.3	17.8 ± 0.7
Height (cm)	171.8 ± 7.0	175.7 ± 6.7	178.4 ± 4.6	180.7 ± 5.1
Body Mass (kg)	59.0 ± 6.9	64.2 ± 7.6	69.1 ± 5.6	73.2 ± 5.9

Data Collection

A validated Italian translation of the CR10 Borg scale was utilized to record each player's sRPE [79, 134, 160]. Data was collected manually from each player in isolation by the teams dedicated fitness coach, this was ~30 minutes following the end of every training session and match performed. All players were familiarized with the validated Italian translation of the Borg Scale before commencing the study [25]. The familiarization process was repeated at the beginning of each competitive season.

Each player's load was also monitored utilizing a short-range telemetry system (Polar Team2 system, Polar Electro, OY, Finland) for HR measurements and a 10 Hz global positioning system (GPS; Viper, Statsports, Ireland). To set individual players heart rate thresholds each team performed a YoYo Test [174] during preseason to determine heart rate max, subsequently every training and match was monitored to verify if the peak value was to be updated. The GPS devices were activated at least 15 minutes before each training session or match and placed in a custom-made pocket between the player's scapulae in a tight-fitting vest. The validity and reliability of these units have previously been shown [175], however, to improve data quality each player was assigned their GPS unit at the beginning of the season to reduce issues related to inter-unit reliability [176]. The data recorded during each session was downloaded utilizing the manufacturer's software (VIPER, Statsports, Ireland) before being stored in a custom-built in-house software. This specific GPS model has previously been documented as valid and reliable, recording small errors even for high-speed activities [175]. Only data recorded in team training sessions were included for analysis, excluding non-representative sessions (e.g., gym-based sessions, individual sessions, post-match top-ups (i.e., additional match-specific training), or rehabilitation work). Match data was included only for players that started the competitive fixture and completed at least 75% of the match. Within the club investigated, the training load variables monitored are consistent across all age groups, from U15 to the First team, facilitating the continuity of the monitoring process and players progressions in different physical parameters. For the analysis, the following variables were selected to quantify load:

Internal Load – sRPE, time spent (min) between 70-85%, 85-90%, and above 90% HRmax; determined as the highest value recorded during the competitive season (i.e., recorded during matches or maximal fitness tests)).

External Load – TD (m), distance covered between 15–20 km/h (HSR, m), 20–25 km/h (VHSR, m) and above 25 km/h (SPR, m), as well as the number of sprints (n), ACC >3 $m \cdot s^{-2}$ and DEC >-3 $m \cdot s^{-2}$.

Statistical Analysis

Linear mixed modelling (with an autoregressive covariance structure) was used to assess the relationship between sRPE and internal and external load variables as fixed effects. For the analysis training and match data from the competitive period were analysed in the same model, with the age group of each participant included and specific to the competitive season. Variables were inspected for abnormal values caused by tracking errors and removed. Linear relationships between the dependent (i.e., sRPE) and predictor variables (3 HR measures and 7 external load measures) were first assessed using Pearson correlations, and highly correlated variables ($r > 0.5$) were removed to avoid multicollinearity. Linear mixed modelling was then used to account for repeated measures over time with an autoregressive covariance structure. Initial null models were run to determine if variation existed in the dependent variable. The final model's residuals were visually examined for normality and examined for outliers by standardizing the residuals into *t*-scores and setting a threshold of >4.5 and re-ran after removal [135]. The reduction of variance between the null model, final model, and individual predictors was assessed.

5.3 Results

Across two competitive seasons, the elite youth academy players participated in 1,436 unique training sessions or matches, providing 25,732 data records. Pearson correlations showed that all independent variables were significantly correlated to sRPE ($p < 0.05$), with TD and HSR both highly correlated with sRPE ($r = 0.549$ and $r = 0.519$, respectively). Seven variables were highly correlated with TD ($r > 0.5$) and were removed from subsequent analyses. The correlation matrix for all variables can be seen in Table 5.2.

Multilevel null modelling showed intercepts did not vary across age-groups (Wald Z = 1.22, $p = .22$) or years (Wald Z = 0.71, $p = .48$) on sRPE. After removing highly correlated variables and 43 outliers, final multilevel modelling showed significant main effects for all three predictors (TD, SPR, and 70-85% HRmax, all $p < .001$). The final model with all three predictors reduced within-participant variance by 46% compared to the null model. Individually entered predictors showed TD reduced within-participant variance by 45.4%, SPR by 24.8%, and time in 70-85% HRmax by 18.8%. Simple effects of the final model can be seen in Table 5.3. The summary of sRPE and predictors by age group and year are presented in Table 5.4.

Table 5.2. Correlation matrix between sRPE and independent predictors.

	sRPE (AU)	**TD (m)**	**HSR (m)**	**VHSR (m)**	**SPR (m)**	**70-85% HRmax (min)**	**85-90% HRmax (min)**	**>90% HRmax (min)**	**Sprints (n)**	**ACC (n)**	**DEC (n)**
sRPE (AU)	1										
TD (m)	0.549	1	-	-	-	-	-	-	-	-	-
HSR (m)	0.519	0.681	1	-	-	-	-	-	-	-	-
VHSR (m)	0.363	0.513	0.641	1	-	-	-	-	-	-	-
SPR (m)	0.332	0.474	0.331	0.477	1	-	-	-	-	-	-
70-85% HRmax (min)	0.084	0.443	0.097	0.099	0.113	1	-	-	-	-	-
85-90% HRmax (min)	0.383	0.579	0.402	0.308	0.242	0.324	1	-	-	-	-
>90% HRmax (min)	0.438	0.526	0.444	0.302	0.266	0.006	0.45	1	-	-	-
Sprints (n)	0.470	0.689	0.724	0.809	0.610	0.143	0.378	0.397	1	-	-
ACC (n)	0.325	0.787	0.306	0.209	0.259	0.561	0.483	0.38	0.358	1	-
DEC (n)	0.341	0.794	0.334	0.230	0.263	0.549	0.492	0.394	0.374	0.992	1

* *r* > .5 bolded, sRPE – session Rating of Perceived Exertion, TD – total distance, HSR – distance covered 15-20 km/h, VHSR – distance covered 20-25 km/h, SPR – distance covered >25 km/h, HRmax – maximum heart rate, ACC – number of accelerations, DEC – number of decelerations.

Table 5.3. Final model simple effects.

	Estimate (Std. Err.)	***t*(df)**	**p**	**95% CI**
Intercept	2.2 (0.05)	42.8 (216.2)	<.001	2.09:2.30
TD	0.0004 (<.0001)	91.9 (24305.8)	<.001	0.0004:0.0004
SPR	0.0017 (0.0001)	11.6 (24299.6)	<.001	0.0014:0.0020
70-85% HRmax	-0.0002 (<.0001)	-18.7 (24442.6)	<.001	-0.0002:-0.0002

TD – total distance, SPR – distance covered >25 km/h, HRmax – maximum heart rate.

Table 5.4. The session Rating of Perceived Exertion (sRPE) and predictors by age group and year.

		sRPE (AU)	**TD (m)**	**SPR (m)**	**70-85% HRmax (min)**
	n	**Mean (SD)**	**Mean (SD)**	**Median (Range)**	**Mean (SD)**
Under 15	5834	4.0 (1.0)	6841 (1940)	13 (0 – 390)	36.7 (13.4)
Under 16	5864	4.6 (1.4)	7114 (2217)	16 (0 – 461)	28.3 (13.8)
Under 17	6429	4.8 (1.5)	7009 (2403)	24 (0 – 766)	30.8 (13.5)
Under 19	7605	4.4 (1.8)	6259 (2696)	16 (0 – 690)	22.5 (11.9)
2017-18	12572	4.7 (1.6)	6783 (2431)	15 (0 – 766)	28.5 (13.0)
2018-19	13160	4.2 (1.4)	6739 (2351)	18 (0 – 690)	31.7 (15.0)
Total	25732	4.5 (1.5)	6761 (2391)	17 (0 – 766)	30.2 (14.1)

TD – total distance, SPR – distance covered >25 km/h, HRmax – maximum heart rate.

5.4 Discussion

Identifying the load variables that affect sRPE can be used to inform training design (i.e., the selection of training activities) and modifications to the training plan. This study aimed to identify the elements of internal and external load that contribute the most towards the sRPE of elite youth soccer players from four different age groups (U15 to U19). The present results identified 3 variables (i.e., TD, SPR, and 70-85% HRmax) which described 89% of the variance in sRPE, supporting the inclusion of load measures that account for total volume, very high-speed activities, and players levels of internal load when planning training based on the resultant sRPE load. Notably, the intercept of the model was not significantly different between any of the four age groups assessed, indicating that the influence of these variables on sRPE did not change with age.

Similar to a recent meta-analysis conducted in team sports [163] and data reduction studies conducted in soccer [61, 177], TD was found to be the variable that described the most variance in sRPE. This finding has been reported in soccer players across different levels of play, from youth [160, 170] to semi-professional [168] and elite level [169]. Furthermore, this finding supports the observation that, in soccer, sRPE-TL is influenced to a greater extent by the training volume than intensity, as relative measures of load (i.e., per minute) have been found to have weaker relationships than absolute metrics [164, 178]. This appears to indicate that the stochastic nature of soccer training and matches, involving both moderate and intense phases [10], impacts perception of fatigue but the quantity of load performed has a greater influence. Collectively, these results highlight the importance for practitioners to consider TD as the strongest contributor to RPE during elite youth soccer players training and match load. This insight can help to prescribe training using TD to modulate load utilizing sRPE, both in a planning phase (i.e., using a session builder) and / or during live GPS monitoring on the pitch.

In the present study, the inclusion of SPR was found to describe the additional variance in sRPE levels (24.8%) compared to TD alone. These observations are supported by previous studies that have reported small-to-moderate relationships between VHSR variables and sRPE in Polish youth soccer players (>19.8 km/h, $r = 0.52$) [170] and semi-professional Spanish soccer players (>18 km/h; $r = 0.64$) [168], while only HSR (>14.4 km/h, $r = 0.61$) was retained in an elite senior level English team [164]. Whilst previous studies have utilized different speed zone classifications, the present observations further confirm that higher-speed activities contribute additional information when programming to meet sRPE goals in youth soccer training and match play. However, the nonlinear relationship between running velocity and the resulting levels of internal load incurred [163] makes it important for practitioners to monitor the frequency with which the high-intensity efforts are performed [168] and individual responses to these higher-speed thresholds [179]. In general, these results align with previous findings and support the inclusion of SPR as an important element of load that practitioners must control within a load monitoring framework for elite youth soccer players.

It is well established that sRPE is related to HR in continuous and intermittent exercise, explaining 12-70% of variation – albeit with a poorer relationship during stochastic activity than continuous activity [180]. In the present study, moderate-intensity HR was found to describe an additional 18.8% of the variance of sRPE than external load metrics alone. These observations support previous suggestions that while both HR and sRPE represent internal load measures they should not be utilized interchangeably [180]. This differentiation is also supported due to the different nature of these internal load measures; a physiological response directly measured from the athlete as opposed to a psychological response of the player to the training load [180]. Others have also reported that HR influences youth soccer players' sRPE [78, 168], with the relationship consistent across all months of the competitive season [180]. However, to date, most studies conducted investigating relationships to sRPE have only assessed external load predictors of sRPE, without evaluating the influence of other objective measures of internal load (i.e., HR) metrics.

The present findings also support that cardiovascular stress influences youth players sRPE. From a practical perspective, these findings further underline the importance of monitoring different constructs of load (i.e., internal, and external load measures) within a planned framework to fully evaluate individual players responses to load. The directionality of the relationship between sRPE and moderate HR (i.e., 70-85% HRmax) provides another important insight, as the negative correlation indicates that inducing lower cardiovascular stress is associated with a lower sRPE in youth soccer players. While this moderate threshold is lower than the average intensity reported during competitive matches (80-90% HRmax) [9] and lower than the 90% HRmax threshold reported to aid improvements in aerobic fitness [81] it does represent the greatest proportion of training [122] due to the stochastic nature of the game, planned recovery periods within sessions and additional stoppages. This finding supports the utilization of HR load measures (e.g., TRIMP measures) compared to time spent within specific individualized thresholds, previously observed to have a large relationship (r = 0.57) with Spanish semi-professional soccer players sRPE load [168]. Thereby supporting the importance of monitoring the volume of HR load recorded, and that practitioners should aim to improve the cardiovascular fitness of youth players, as this can aid to reduce the intensity of internal load recorded for the same quantity and intensity of external load performed.

The intercept of the linear mixed models applied in the present study does not change between the four age groups investigated, indicating that the mean sRPE recorded does not differ significantly as players progress through the academy. The limited variation observed in sRPE values recorded during soccer training [178, 181] may be attributed to the modification of training content according to the players developmental age [37]. This is also likely explained, in part, by the development of their anaerobic and neuromuscular characteristics [173, 182, 183]. This observation facilitates the design of training plans and load monitoring procedures for practitioners as the influence of the three variables to control (TD, SPR, and 70-85% HRmax) and their contribution to sRPE remain consistent across the entire academy system.

Whilst the present study identifies a restricted number of load variables to evaluate during the training planning phase, facilitating the use of a session builder tool for sRPE modulations, it does however have some limitations that must be considered. Despite a large number of players, training sessions, and matches included from across different age groups, they all derive from the same elite-level youth academy, which may limit the generalisability of the present findings. Including different training modes and matches and periods of the season in the same analysis may also have impacted the nature and strength of relationships recorded [163, 164, 184]. In the present study, no individual thresholds of external load were included, further investigation can assess whether these are more appropriate for younger age groups than standard thresholds. The assessment of inter-subject variability and influence of playing position may also help to provide further insights. Furthermore, once relationships between load measures are established, future studies should aim to determine which of these load variables induce positive training outcomes by conducting training dose-response studies.

Our findings, when taken with others, support the prescription of training using a more parsimonious selection of variables to manage within a load monitoring framework. Closely monitoring elite youth players TD, periodizing exposure to SPR, and monitoring HR responses to the physical stimuli is essential for the modulation of load. Utilizing a combination of these internal and external load measures appears to be the most comprehensive approach for influencing the sRPE of elite youth soccer players. Establishing the greater influence of volume over intensity can also aid practitioners to implement an evidence-based approach to the design of training interventions within an academy system. The use of a drill database and session builder prediction tool can integrate these findings during the decision-making process and help to inform and adapt future training.

CHAPTER SIX

Study Five: Training load variables in elite youth soccer: is a data reduction approach consistent across different age groups?

Chapter preface

This study assessed all the training load variables recorded by wearable micro-technology to identify a reduced number of metrics that can describe the largest amount of variance being recorded in the dataset. A data reduction approach was utilized to create a more parsimonious number of variables that can be evaluated during the training planning phase and for providing feedback to coaches for a specific session or training period. These results of the data reduction procedure did not achieve a sufficiently reduced dataset and retained diverse elements of training load. Furthermore, inconsistencies between the load variables retained and their relative importance indicate that the present findings are not practically useful for an entire academy approach. However, the identification of key themes across the four age groups attests to the importance of including these constructs as part of an elite youth soccer player monitoring programme.

6.1 Introduction

Wearable microtechnology has significantly impacted athlete development and player care programs in elite-level soccer clubs and their youth academies. The information provided by these devices can grant important insights into the quantity and nature of training being performed by each player [18, 75]. A key issue for practitioners is the ability to handle the increased quantity of data provided by the sensors (and algorithms) housed within these devices. Indeed, the training load measures selected must provide meaningful information on different constructs of load [28, 157, 158]. When appropriate variables are selected, this information can then be utilized to aid the decision-making process relating to future training activities, to improve players fitness and reduce their risk of injury [130].

Currently, commercially available GPS units can provide large amounts of data across a great number of different velocity and duration-derived metrics, often reported in different intensity thresholds [26, 75]. However, the large amount of data provided by these devices also poses an issue, as a large quantity of the data may be redundant and confound the athlete monitoring process. Data reduction techniques can be applied to identify a smaller number of variables that describe the largest degree of variance in load and help to avoid data redundancy [162]. Principal component analysis (PCA) has become a popular method for data reduction in soccer and other team sports [61, 159, 185-187]. PCA identifies variables that describe unique information within the dataset and establishes their relative contribution toward the variance recorded [162, 188]. This multivariate statistical technique analyses several dependant variables that are often inter-correlated, with the goal of extracting the main variables and creating new variables, known as principal components [189]. These approaches to data reduction can be applied to streamline the data analysis process, allowing practitioners to dedicate more time to the interpretation of the data [188] and facilitate the communication of actionable insights to the coaches [158].

To date, PCA has been applied to assess a wide range of different aspects relating to football match outcomes and training load measures. In general, PCA has been a useful method for the reduction of variables retained in the analysis of players and team's tactical behaviour, GPS-derived measures of load, and variables recorded during physical tests (e.g. jumps, change of direction, agility, etc.) [187]. Studies using PCA to assess training load in soccer have shown variables included in the principal components (PCs) and their weightings to change across different training game formats (e.g., small-, medium- and large-sided games) in professional adult players [190]. In addition, the variables identified from training activities were different from those retained from official matches [190], highlighting the different nature of these activities and the complexity of the variable selection process. Interestingly, PCA results also differed between training days in an elite Scottish youth academy [61], suggesting a periodized approach across a weekly training micro-cycle, aimed at optimizing athletes' performance levels [145]. The number of PCs identified changed from two to three according to how high-intensity variables were split (i.e., HSR and ACC) in the lead-up to the next competitive fixture [61]. However, these studies were conducted by assessing only the data relating to one specific age group [61, 187, 190].

It is not currently known if PCA outcomes are consistent across different age groups of an elite youth soccer academy. If the components derived from PCA and their factor loadings remain consistent between age-groups (i.e., from U15 – U19), it would provide support for utilizing this approach. This would allow for a simplified, single academy approach that would allow for an effective reduction in the training load monitoring variables assessed within an academy. In contrast, if the PCA outcomes vary between the age-groups this approach would not be a suitable technique to apply across a whole academy. The identification of different principal components (with different loading factors within each component) would require a separate PCA to be developed for each age group and from a practical perspective, would unnecessarily complicate the process of analysing training data. At present, it is not yet known if a PCA of training load variables remains stable or if they change with age, squad group, or playing level. Assessing this specific aspect is essential for assisting practitioners in effectively identifying the metrics to take into consideration for the design and management of training programs.

Therefore, this study aimed to reduce the number of variables assessed within a player monitoring program. A PCA was applied to identify collinear measures within the dataset and create PCs that can describe the greatest degree of variance in this specific population [8, 9]. A secondary aim was to verify the consistency of the retained variables across different age groups of an elite youth soccer academy (U15-U19).

6.2 Methods

A longitudinal observational study design was employed to evaluate data collected as part of an athlete monitoring program. Individual players training and match metrics were recorded over 45 weeks (comprising the preseason and in-season phases) for 2 complete competitive seasons (2017-2018 and 2018-2019). This approach, comprising both training and match data, was selected to identify one selection of reduced variables that can be applied for monitoring all sessions. For the analysis, multiple PCA's were performed to evaluate the repeatability of the outcomes across the four different age groups, U15 to U19.

Participants

One hundred and forty-five elite youth soccer players belonging to the U15 to U19 squads of the same soccer academy participated in this study. To be eligible for this study the players simply had to have completed at least one full training week with their squad and all monitoring data collected. The player's anthropometric measures are presented in Table 6.1. Before the commencement of each season written informed consent was obtained from each player and their legal guardian. The study was approved by the University Research Ethics Committee (UTS HREC ETH19-4420).

Table 6.1. Players' anthropometric measurements across 5 competitive seasons (mean ± SD).

	Under 15	**Under 16**	**Under 17**	**Under 19**
n	46	44	40	75
Age (y)	14.4 ± 0.3	15.4 ± 0.3	16.4 ± 0.4	17.9 ± 0.7
Height (cm)	173.6 ± 6.8	176.1 ± 6.1	179.7 ± 6.4	180.5 ± 5.0
Weight (kg)	63.0 ± 6.9	66.2 ± 7.1	71.4 ± 4.8	73.6 ± 5.4

Data Collection

Every training session and match performed by the youth academy players was monitored utilizing a 10 Hz GPS device with a 100 Hz 3-D accelerometer, a 3D gyroscope, a 3-dimensional digital compass (VIPER, Statsports, Ireland), and a heart rate monitor (Polar Team2 system, Polar Electro, Finland). Each player was assigned their own devices (GPS and cardio) at the start of the season to reduce any issues related to inter-unit reliability [176]. The GPS devices were activated at least 15 minutes before each session and placed in a custom-made pocket between the players scapulae in a tight-fitting vest.

All data collected from each session was downloaded utilizing the manufacturer's software (VIPER Version 2.1.125, Statsports, Ireland) and subsequently stored in a custom-built in-house software.

A subjective measure of players' load was also recorded utilizing the sRPE method; calculated by multiplying the players perception of effort, using the Borg CR10 scale [79, 134], with the duration of the session [134]. The players sRPE was collected ~30 min following each training session and match performed by the team's fitness coach. All players were familiarized with the validated Italian translation of the Borg Scale before commencing the study [25].

For the analyses, we included all of the parameters recorded by GPS, HR monitors, and RPE values, for a total of 82 variables. The GPS devices utilized in this study have previously been shown to be valid and reliable for monitoring distances and peak speed [191]. The variables and their description (including thresholds) are summarized in Table 6.2. The content of the training sessions was prescribed by the club coaching staff throughout the period assessed.

Statistical Analysis

Four PCA were performed to reduce the dimensionality of all the training load parameters collected daily, identifying the variables that record similar or unique information for each age group. This approach ensures that the variables identified are effectively those that describe the greatest degree of variance recorded, helping to identify metrics or a specific construct of load. All variables were inspected for abnormal values caused by tracking errors and removed. Only data relating to representative team training sessions were included for the analysis to reduce the number of outliers (i.e., including all available players and a duration >30 min, thereby removing rehabilitation and top-up sessions). Within each age-group outliers were removed (± 3 SD) to reduce their effects on the correlations which PCA is based upon and scaled ($z = (x-u)/s$). Pairwise Correlations showed missing data of 0.03% across all variables and age groups.

Pairwise correlation matrixes were examined within each age group and a variable was removed if it shared a correlation larger than $r = 0.7$ with another variable. Retention priority was given to variables with the largest number of correlations to reduce factors as much as possible. Where possible efforts to retain similar variables across age groups were made. PCA analysis with Varimax rotation was conducted for each age group across the two seasons of data. Bartlett's sphericity test and Kaiser-Meyer-Olkin (KMO) tests were examined to ensure the data was suitable for PCA [158]. Factors were extracted when Eigenvalues were greater than 1. Retained variables were examined descriptively across the different age groups. The Statistical analysis was conducted in R statistical software (version 3.6.3) (R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2019).

Table 6.2. Training load variables recorded during each training session and match divided into macro-categories.

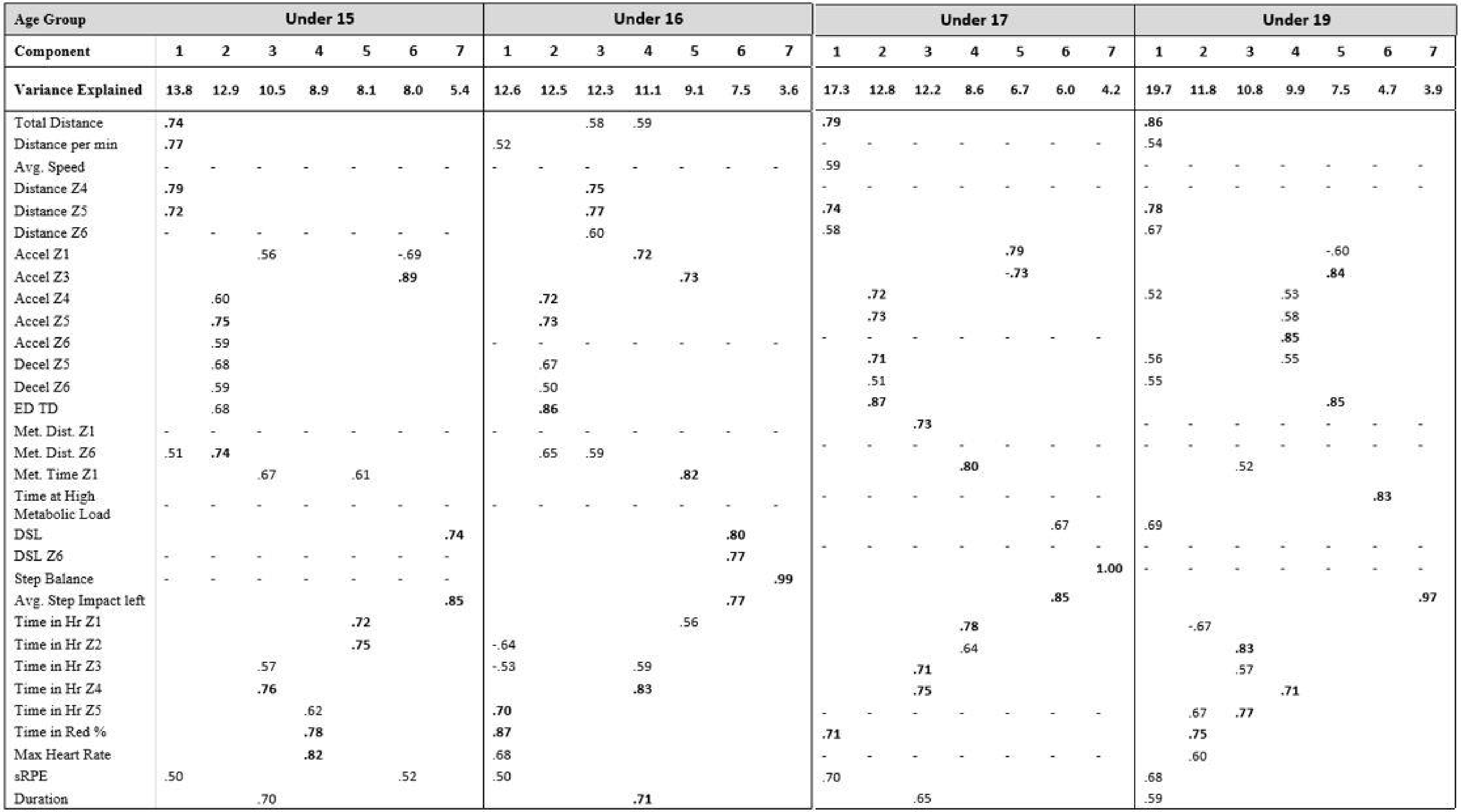
Category	Variable	Measure	Definition
Volume	Total Distance	m	Total distance covered
	High-Speed Running	m	Distance covered above 20 km/h
	Energy Expenditure	kcal	Number of calories consumed
	Equivalent Metabolic Distance	m	Distance covered at constant speed to expend the same amount of energy expenditure
	High-Metabolic Load Distance	m	Distance covered >25.5 W/kg
	Explosive Distance	m	Distance covered > 25.5 W/Kg and below 20 km/h
	Speed Intensity	AU	Total exertion based on the time spent in each of the speed values
	Dynamic Stress Load	AU	Total of weighted impacts >2 g
	Heart rate exertion	AU	Total exertion based on weighted heart rate values
Events	High-Metabolic Load Efforts	n	Total of efforts performed above 25.5 W/Kg
	Impacts	n	Total of body impacts >2 g in a 0.1 s period
	Accelerations	n	Total of accelerations recorded >2.5 $m.s^{-2}$ for at least 0.5 s
	Decelerations	n	Total of decelerations recorded >-2.5 $m.s^{-2}$ for at least 0.5 s
	Sprints	n	Total of actions above 20 km/h that lasted at least 1 s
Zones	Distance in Speed zones	m	Distance covered in 6 speed zones (0-6 km/h, 6-9 km/h, 9-15 km/h, 15-20 km/h, 20-25 km/h, 25-40 km/h)
	Metabolic Distance Zones	m	Distance covered in 6 zones (0-5 W/kg, 5-1 W/kg, 10-15 W/kg, 15–25.5 W/kg, 25.5–50 W/Kg, 50-500 W/Kg)
	Speed Intensity Zones	AU	Running Exertion in 6 zones (0-1.5 m/s, 1.5-3 m/s, 3-4m/s, 4-5.5m/s, 5.5-7 m/s, 7-11 m/s)
	Dynamic Stress Load Zones	AU	Weighted impacts in 6 zones (3-5 G, 5-7 G, 7-9 G, 9-11 G, 11-13 G, 13-15 G)
	Impact Zones	n	Total of body impacts recorded in 6 zones (3-5 G, 5-7 G, 7-9 G, 9-11 G, 11-13 G, 13-15 G)
	Accelerations	n	Number of Accelerations in zones (0-2 m/s^2, 2-2.5 m/s^2, 2.5-3 m/s^2, 3-4 m/s^2, 4-5 m/s^2, 5-10 m/s^2)
	Decelerations	n	Number of Decelerations in zones (0- -2 m/s^2, -2- -2.5 m/s^2, -2.5- -3 m/s^2, -3- -4 m/s^2, -4- -5 m/s^2, -5- -10 m/s^2)
Time	Duration	min	Total duration of the session
	Heart rate zones	min	Time Spent in 6 zones related to each individual player's heart rate max (0-50%, 50-60%, 60-70%, 70-85%, 85-90%, 90-120%)
	Time in Red Zone	min	Time Spent above 85% heart rate max threshold
	Time in Metabolic Distance Zones	min	Time Spent in 6 zones (0-5 W/kg, 5-1 W/kg, 10-15 W/kg, 15–25.5 W/kg, 25.5–50 W/Kg, 50-500 W/Kg)
	Time at High-Metabolic Load	min	Time spent above 25.5 W/Kg
Maximum	Heart Rate Max	bpm	Maximum heart rate value recorded
	Max Speed	km/h	Maximum running velocity recorded
Average	Distance	m/min	Average distance covered per minute
	Average Heart Rate	bpm	Average heart rate recorded
	Average Speed	km/h	Average running velocity recorded
	Average Metabolic Power	W/Kg	Average energy expended kg/s
	Average Step Impact	%	Average of the left and right foot impacts
	Step Balance	%	Asymmetry value between the intensity of and left right steps
Subjective	sRPE	AU	Session Rating of Perceived Exertion
	sRPE-TL	AU	Session Rating of Perceived Exertion training load

6.3 Results

Data from the two competitive seasons included 30 central defenders, 52 central midfielders, 35 wingers, and 28 attackers. These players participated in 416, 433, 498, and 540 training sessions or matches over the two seasons, equating to 6051, 5921, 6511, and 8340 individual GPS files. After removing highly correlated variables, 27, 28, 24, and 26 variables (for U15-U19, respectively) were used in subsequent PCAs for each age group. All four PCAs presented below reported acceptable KMO values (0.756 - 0.802) and recorded significant Bartlett's tests ($p < 0.001$).

Seven components were extracted after rotation across all four of the PCAs. The component loadings and the variables retained for each age group are presented in Table 6.3. The components included 23 variables that loaded consistently across the different age groups and 7 variables that loaded inconsistently. The variables retained consistently include total distance, speed zones, accelerations and deceleration zones, heart rate intensity and limited variables relating to metabolic power measures. The components in which the variables loaded, and the strength of loadings, differed across each age group. The sum of the 7 components explained 67.6%, 68.7%, 67.8%, and 68.3% of the variance recorded in training and matches across U15 to U19 age groups, respectively. Component number 1 explained 12.6─19.7% of the variance, with its weighting increasing slightly in the older age groups.

Table 6.3. PCA component loadings by age group.



Age Group	**Under 15**							**Under 16**							**Under 17**							**Under 19**						
Component	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Variance Explained	**13.8**	**12.9**	**10.5**	**8.9**	**8.1**	**8.0**	**5.4**	**12.6**	**12.5**	**12.3**	**11.1**	**9.1**	**7.5**	**3.6**	**17.3**	**12.8**	**12.2**	**8.6**	**6.7**	**6.0**	**4.2**	**19.7**	**11.8**	**10.8**	**9.9**	**7.5**	**4.7**	**3.9**
Total Distance	**.74**									.58	.59				**.79**							**.86**						
Distance per min	**.77**							.52							-	-	-	-	-	-	-	.54						
Avg. Speed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.59							-	-	-	-	-	-	-
Distance Z4	**.79**									**.75**					-	-	-	-	-	-	-	-	-	-	-	-	-	-
Distance Z5	**.72**									**.77**					**.74**							**.78**						
Distance Z6	-	-	-	-	-	-	-			.60					.58							.67						
Accel Z1			.56			-.69					**.72**								**.79**							-.60		
Accel Z3						**.89**						**.73**							**-.73**							**.84**		
Accel Z4		.60							**.72**							**.72**						.52			.53			
Accel Z5		**.75**							**.73**							**.73**									.58			
Accel Z6		.59						-	-	-	-	-	-	-	-	-	-	-	-	-	-				**.85**			
Decel Z5		.68							.67							**.71**						.56			.55			
Decel Z6		.59							.50							.51						.55						
ED TD		.68							**.86**							**.87**										**.85**		
Met. Dist. Z1	-	-	-	-	-	-	-	-	-	-	-	-	-	-			**.73**					-	-	-	-	-	-	-
Met. Dist. Z6	.51	**.74**							.65	.59					-	-	-	-	-	-	-	-	-	-	-	-	-	-
Met. Time Z1			.67		.61							**.82**						**.80**						.52				
Time at High Metabolic Load	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						**.83**	
DSL							**.74**						**.80**							.67		.69						
DSL Z6	-	-	-	-	-	-	-						**.77**		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Step Balance	-	-	-	-	-	-	-							**.99**							**1.00**	-	-	-	-	-	-	-
Avg. Step Impact left							**.85**						**.77**							**.85**								**.97**
Time in Hr Z1					**.72**							.56						**.78**					-.67					
Time in Hr Z2					**.75**			-.64										.64						**.83**				
Time in Hr Z3			.57					-.53			.59						**.71**							.57				
Time in Hr Z4			**.76**								**.83**						**.75**								**.71**			
Time in Hr Z5				.62				**.70**							-	-	-	-	-	-	-		.67	**.77**				
Time in Red %				**.78**				**.87**							**.71**								**.75**					
Max Heart Rate				**.82**				.68							-	-	-	-	-	-	-		.60					
sRPE	.50					.52		.50							.70							.68						
Duration			.70								**.71**						.65					.59						

Bold – loadings > 0.7. min – minutes, Avg. – average, Z – zone, Accel - number of accelerations, Decel – number of decelerations, ED – equivalent distance, TD – total distance, Met. Dist. – metabolic distance, DSL – dynamic stress load, Hr – Heart rate, % - percentage, sRPE – rating of perceived exertion.

6.4 Discussion

This study aimed to reduce the number of variables assessed in the player monitoring program of an elite youth soccer academy by applying a PCA. A secondary aim was to verify the consistency of the retained variables across the different age groups (U15-U19). The main results revealed that a PCA reduced the number of variables retained, but there were numerous inconsistencies in which variables loaded and how they loaded across the different components between the different age groups, indicating that a one-size fits all approach is not applicable.

The present study is the first to apply a PCA to a wide array of internal and external training load measures collected during soccer training and matches across four different age groups of an elite youth soccer academy. In general, the number of PCs extracted from the present data set (n = 7) was similar to previous studies conducted in soccer (an average of 6.4 extracted factors) [187]. However, the seven PCs derived from the present analysis are greater than previous studies that specifically assessed training load in soccer, particularly if conducted using a limited number of pre-selected variables (i.e., 7-15) [61, 185, 192]. The present analysis identified 23 variables that were consistently retained across the four age groups, however, there were differences between the different age groups (range: 24 – 28 parameters) and their respective loadings. In general, this represents less than a third of the 82 variables recorded and included in the present analysis. An issue that practitioners must face, beyond the quantity of the data recorded, is the limited evidence regarding the validity and reliability of many of these variables [175, 176, 193].

The PCA outcomes accounted for a similar amount of variability (67.6—68.7%) and the number of training load metrics to a previous study including both internal and external load measures collected over one complete season [194]. However, the variance recorded in the first component was substantially lower than previous reports from professional soccer players (36-44%) [177, 185, 190]. This finding also contributes to the variability described being more stable across different components (i.e., 3-4 components per age group describing >10% variance). Interestingly, in the U16 age group, there does not appear to be a clear component that describes a greater degree of variance, with the first 3 PCs all accounting for 12.3 – 12.6% of the total variance. Collectively, this highlights that no single variable can be selected to accurately reflect all training and competition demands in youth soccer.

The complex nature of soccer training and match-play requires a combination of different load variables to describe the variance recorded in the player’s physical load [61, 185, 187, 190]. Incorporating different constructs of load (i.e., cardiovascular, locomotor, and neuromuscular) is required to fully describe the different physical demands placed upon players during training and matches [185]. The PCA outcomes from the current training load data set revealed similar general themes and constructs of load to previous PCA studies, despite the age differences, playing level, and the number of variables included in the analysis [61, 177, 190, 192, 194-196]. Across the four age groups, the components generally relate to 1) training volume and high-speed running, 2) high ACC load, 3) high-intensity HR, 4) low-to-moderate intensity load; and 5) accelerometer-based measures. The retention of these different elements attests to the stochastic nature of soccer and the numerous different physical capabilities elicited [8, 10]. They also allude to the importance of monitoring and periodizing these factors within a planned training regime [20]. However, despite generally consistent themes relating to volume and intensity components, the PCs do have subtle but important differences in the variables retained and their loading factors between the different age groups. This lack of stability in PCA outcome variables indicates that practitioners should select variables according to a conceptual framework.

To the author's knowledge, no previous study has assessed the consistency of PCs created from training load data collected in an elite youth academy. These present findings show that total distance was the variable that consistently had the most correlations with other load measures and explained the greatest amount of variance for three of the four age groups (first principal component (PC1) for U19-U17-U15). This is likely due to the importance of training volume (i.e., total distance covered) on the overall load of a session and this specific parameters elevated number of correlations with other external load variables recorded by GPS devices [61, 177]. Interestingly, in the present study high-speed running variables were found to load alongside total distance in all age groups. This finding was similar to some previous studies [61, 194] but not consistent, as several others have reported high-speed running to capture unique additional information in soccer training and match play [162, 185, 190, 197]. Given the importance of monitoring high-speed running in literature [132, 198, 199], this finding poses a significant quandary relating to the approach applied to interpreting the components (i.e., selecting 1 variable or a summed variable) and the practical implications and limitations related to this choice [10]. The inconsistencies observed in the high-speed running variables retained across the different age groups could be attributed to changes in physical capacity, conceptually due to the development of anaerobic and neuromuscular characteristics as they progress through the youth academy [200]. Indeed, in the present study, the Under 15 age group did not retain the highest high-speed zone (>25 km/h), with Under 16 appearing to be a transition age group prior to both Under 17 and Under 19 retaining this highest threshold and no longer loading the lowest high-speed threshold (distance covered above 15 km/h). The use of absolute thresholds and the individual nature of the levels being recorded by players during training and matches may pose another issue relating to the consistency of variables retained. Unfortunately, comparisons of external load variables with previous studies are difficult due to the utilization of different thresholds (both in terms of speed and the utilization of absolute or relative thresholds) [159, 185, 197].

High ACC loads also appear to be another main factor, loading consistently in PCs and accounting for 10-13% of the variance across all age groups. This is likely related to the numerous explosive and intense actions required during soccer-specific movements in both training and competition [8]. However, the number of accelerative events recorded, and consequently how they load within a PCA appear to be coach or team dependent, as well as being influenced by the type of training sessions performed [61, 190]. Interestingly, several accelerometer-based parameters (e.g., step balance, step impact, and dynamic stress load) were found to load independently of other internal and external load metrics, accounting for 3.9─7.5% of the variance. This observation highlights that these measures, recorded by inertial sensors incorporated within the wearable devices, contribute additional information to the traditional velocity metrics. These results are slightly lower than previously reported in professional Spanish football, where dynamic stress load and the number of impacts accounted for 14 to 20% of differences between training game formats [190]. However, like other measures, the variables retained recorded inconsistent relationships in the variance they described across the PCs and different age groups, further attesting to the need for caution when generalizing PCA outcomes.

The present results show that HR measures capture additional information than GPS and accelerometer-derived data, as different thresholds were consistently retained in each age group. This finding is supported by one study in semi-professional football that found time spent >80% maximum HR provided unique information, not described solely by external load measures [185]. In general, these findings support the inclusion of HR metrics and reporting of different HR intensity zones in the player monitoring program. However, despite the positive relationship reported between HR indicators and changes in physical fitness [58] most previous studies conducted in soccer using PCA failed to report any HR variables.

In the present study, the sRPE was consistently associated with the quantity and intensity of running performed in the PC1. This is in agreement with previous PCA studies in soccer that identified sRPE as a volume-based measure [61, 192] and a recent meta-analysis conducted on team sports that highlighted the strength of correlations for total distance was greater for internal load than for high-intensity running thresholds [163]. Collectively these findings demonstrate that high levels of collinearity can exist between different constructs of load (i.e., internal and external load indicators [75]). Furthermore, in three of the four age groups, sRPE was found to load in different components to training duration, while sRPE-Training Load did not load in any of the youth academy PCs. This observation supports the recording of both sRPE and duration separately, as they appear to measure separate constructs of load, providing a greater degree of information than the combined sRPE-Training Load variable.

Whilst we have included many training load variables in this study it is not exhaustive of all load measures or thresholds (i.e., absolute, and relative) that can be monitored. Like previous studies, the retention of variables highlights the human decisions that are made when examining multiple pairs of highly correlated variables for inclusion in the PCA. In addition, differentiating training periods (e.g., daily, weekly, monthly, preseason) may also be required to effectively identify the variables that consistently record the greatest degree of variance [61, 192]. A further limitation of the present study relates to the utilization of repeated measures in the PCA analyses. Future studies may evaluate further subdivisions within the different age groups (e.g., player role, starter vs non-starter, etc.). Multi-team studies may also aid to increase the statistical power and provide a clearer picture of which variables and load constructs describe the most variance in youth soccer players. In addition to this, future studies should also evaluate and compare this statistical method to other approaches, including machine learning techniques (i.e., development of algorithms that perform intellectual processes).

Conclusions & Practical Applications

PCAs were applied to reduce the number of training load parameters taken into consideration during the player monitoring program and consequently the decision-making process relating to the training load prescribed in an elite youth soccer academy. Whilst the analyses effectively reduced the number of variables retained, the PCs were different between age groups and the loadings of variables were inconsistent across PCs. These observations suggest that it is not practical or appropriate to generalize the outcomes of a PCA (e.g., differences across speed, ACC, and HR zones) across an entire youth academy. Whilst a reduced set of variables obtained from a PCA initially appeared as an attractive proposition, the number of retained variables after the analysis (i.e., retention of 25 different metrics) does not appear to be sufficiently parsimonious for use in daily practice. The present findings suggest that these differences in PCs are likely group-dependent and would require practitioners to repeat this analysis each season, potentially resulting in the variables utilized for training monitoring changing between competitive seasons. Nonetheless, the identification of general themes that emerge from the data reduction analysis supports the use of different constructs of load (i.e., internal, and external load) to effectively capture the greatest degree of variance. The constructs of load and variables retained align closely with soccer's game model, thereby essentially providing practitioners with the building blocks to be included and evaluated within an elite level player monitoring program. This process of identifying which variables are important and why they are being monitored utilizing an evidence-based approach is becoming increasingly important in applied settings. Therefore, it is recommended that practitioners create a conceptual framework, comprising different constructs of load, from which to base the selection of variables considered within the clubs' monitoring system.

CHAPTER SEVEN

Study Six: Identifying training load variables through a conceptual framework for elite youth soccer

Chapter preface

This study addressed some of the issues identified in study five regarding data reduction approaches. A conceptual framework was devised to establish the main constructs of load to be included in the analysis, identifying load variables from within the macro-areas identified through a needs analysis, previous literature, and expert opinion. This guided approach to data reduction identified four key themes within each age group, with variance distributed evenly across each of these components. These findings support the inclusion of different constructs of load (i.e., external & internal) and different aspects of load (i.e., volume and intensity) in a youth football player monitoring system. The present findings show that practitioners can identify key load measures through the conceptual framework, as the statistical data reduction approach did not contribute to further reducing the number of variables.

7.1 Introduction

The continual development and pervasiveness of athlete monitoring technologies (e.g., wearable microtechnology) has greatly facilitated the quantification of internal and external load performed by senior and youth soccer players during training and matches [28, 33]. These advances have also resulted in a large quantity of data being recorded across a wide range of different load measures [26, 187]. From a practical perspective, practitioners require that these large data sets be reduced to a parsimonious number of variables that can then be used to inform the training prescription process [157, 187]. Reducing the dimensionality of the data collected can directly aid the interpretability of the variables, the decision-making process relating to future training, and lower the time required to assess and interpret these data.

A PCA is a widely applied statistical technique to objectively reduce the number of variables while describing a large percentage of the variance within a dataset [187]. In soccer this approach has previously been employed utilizing a large number of input variables (n = 51.4), to identify key performance indicators [187]. We have previously used this approach on all GPS and HR variables recorded during training sessions and matches, however whilst this approach reduced the initial dataset (i.e., from 80 variables to 25, divided across 7 components) the results were limited in their practical application because the number of variables retained was still too large to utilize daily and no metric (or group of variables) clearly described the most variance in the dataset. Other similar studies that applied PCA to reduce load monitoring in soccer appear to have used domain knowledge to guide the selection of variables before conducting PCA, as a restricted number of input variables have been included in the analyses (n = 8–11) [61, 192, 194]. The application of a guided approach to select variables to be included in such analyses (i.e., based on existing literature, conceptual frameworks [48, 62, 63, 75], and professional expertise) may help to reduce the data more effectively. Conceptual frameworks help researchers and practitioners to synthesize evidence and assists with the understanding of the relationships between different factors and moderators being investigated, aiding the explanation of a particular phenomenon [62]. This approach can help to visualize and conceptualize the links between different constructs of load, for example internal and external load [22, 62] .

Determining the variable selection procedure is essential because it can significantly impact the outcomes of the data reduction analysis and subsequently limit comparisons between studies [201].

Based on the conceptual frameworks currently available [48, 62, 63, 75] any data reduction analysis should include different constructs of load to ensure that they are describing the intermittent nature of soccer and all of the physical stressors the athletes are exposed to [8, 27]. This needs analysis approach to the inclusion of variables in a PCA is of particular importance if you consider the relationships that have been documented between load and performance [163] and injury risk [49, 202].

To date, the studies that have applied PCA to soccer load variables have each identified components representing similar general constructs of training load, mainly relating to the volume and intensity of load performed [61, 177, 190, 192]. These findings indicate that no single load variable can capture all the variance recorded and support the inclusion of total distance, high-speed running, and ACC measures. Interestingly, relating to these aspects, the impact of including absolute or relative load variables (i.e., divided by time) has also yet to be evaluated. Despite internal load being a moderator of training outcomes, few studies have included any of these measures in PCA, with four studies only reporting the player sRPE, [61, 177, 190, 192] and none reporting HR measures. In addition, the variables retained for youth soccer players have been observed to vary across the different training days of a weekly training microcycle, as well as during different phases of the competitive season [61, 192]. However, differences between the different age groups of an elite youth academy have yet to be assessed.

Therefore, this study aimed to employ a guided approach to the reduction of variables assessed within an elite youth soccer player monitoring program and verify the consistency of the metrics retained and the variance they described across different age groups (U15-U19). A secondary aim was to evaluate whether absolute or relative load measures described more variance within the dataset.

7.2 Methods

A conceptual framework based on current best evidence in literature and expert opinion was created specifically for this study, to guide the selection of internal and external training load variables that were included in a player monitoring program of an elite-level youth soccer academy. These selected variables were then collected across two competitive seasons (including preseason and in-season periods) before data reduction via PCA. This process was undertaken to identify the key variables and their weightings within the dataset, as well as the consistency of principal components created across the 4 different age groups (U15-U19). A further sub-analysis focused on the comparison of absolute metrics to relative metrics (i.e., the total quantity of load recorded vs. the intensity of a session, dividing the volume of load by duration).

Participants

A total of 145 elite youth soccer players from the same elite level youth academy participated in this study during the 2017-2018 and 2018-2019 competitive seasons. To be eligible for this study the players had to have completed at least one full training week with their age group squad and have all monitoring data collected within that period. The player's anthropometric measures are summarized in Table 7.1. Written informed consent was obtained from each player and their legal guardian before the beginning of each competitive season.

Table 7.1. Player's anthropometric measurements (mean ± SD).

	Under 15	**Under 16**	**Under 17**	**Under 19**
n	46	44	40	75
Age (y)	14.4 ± 0.3	15.4 ± 0.3	16.4 ± 0.4	17.9 ± 0.7
Height (cm)	173.6 ± 6.8	176.1 ± 6.1	179.7 ± 6.4	180.5 ± 5.0
Body mass (kg)	63.0 ± 6.9	66.2 ± 7.1	71.4 ± 4.8	73.6 ± 5.4

Data Collection

The training loads (internal and external) completed [75] by the elite youth players was recorded during every training session and match via HR monitors (Polar Team2 system, Polar Electro, OY, Finland) and a 10 Hz GPS device with a 100Hz 3-D accelerometer, a 3D gyroscope, a 3D digital compass (VIPER, Statsports, Ireland). To minimize any issues related to inter-unit reliability [176] each player, across the four age categories, was given their own devices (GPS and cardio) at the start of each competitive season. All the tracking devices were activated for 15 minutes and placed into the custom-made pocket, positioned between the players scapulae of a tight-fitting vest, before the commencement of each pitch-based session. The data from each session was downloaded utilizing the manufacturer's software (VIPER Version 2.1.125, Statsports, Ireland) and stored in a custom-built in-house software (Juventus Area Tecnica, Italy). In addition, the CR10 Borg scale [79, 134] was also utilized to record the players session rating of perceived exertion (sRPE). All players were familiarized with the validated Italian translation of the Borg Scale at the beginning of each competitive season [25]. The sRPE of every training and match was collected on an individual basis, asking players to utilize the verbal queues on the scale, ~30 min following the end of a session. The sRPE value was later multiplied by the duration of the session [134]. Throughout the two competitive seasons, the content of the training sessions was prescribed by the specific age group coaching staff.

Analysis

Before employing a PCA for data reduction a conceptual framework was devised for the selection of the variables to be included in the daily monitoring program of an elite-level youth football academy. This selection of variables was guided by expert opinion and previous literature [8, 22, 48, 63], including both internal and external training load measures [75]. This process involved the identification of the different constructs of load to include and physical requirements linked to physical performance in soccer to be included. The following step included the evaluation of which variables were readily available through daily monitoring (i.e., microtechnology and subjective measures) and were retained in the previous PCA (see Chapter 6). The list of variables could differ slightly if conducted with different GPS providers or load monitoring devices. A short list of moderators of that can influence the relationships with training outcomes (evaluated in the next study) were also selected.

Two distinct PCAs were then conducted to ascertain if there were any differences in the variables retained and their respective weightings if practitioners utilized measures of volume (i.e., total load; Absolute PCA) or the intensity of a session (i.e., metres per minute; Relative PCA). A total of 16 load variables were retained for the Absolute PCA, while only 14 variables (removing duration and peak speed) were retained for the Relative PCA. The conceptual framework, presented in Figure 7.1, including measures relating to volume and intensity across different constructs of load (i.e., internal and external load), was developed from available literature [8, 22, 48, 75], soccer physical demands [63] and informed by expert feedback (i.e., professionals with >20 y experience in elite level soccer, Head of Performance within the club and experts in the academic field).

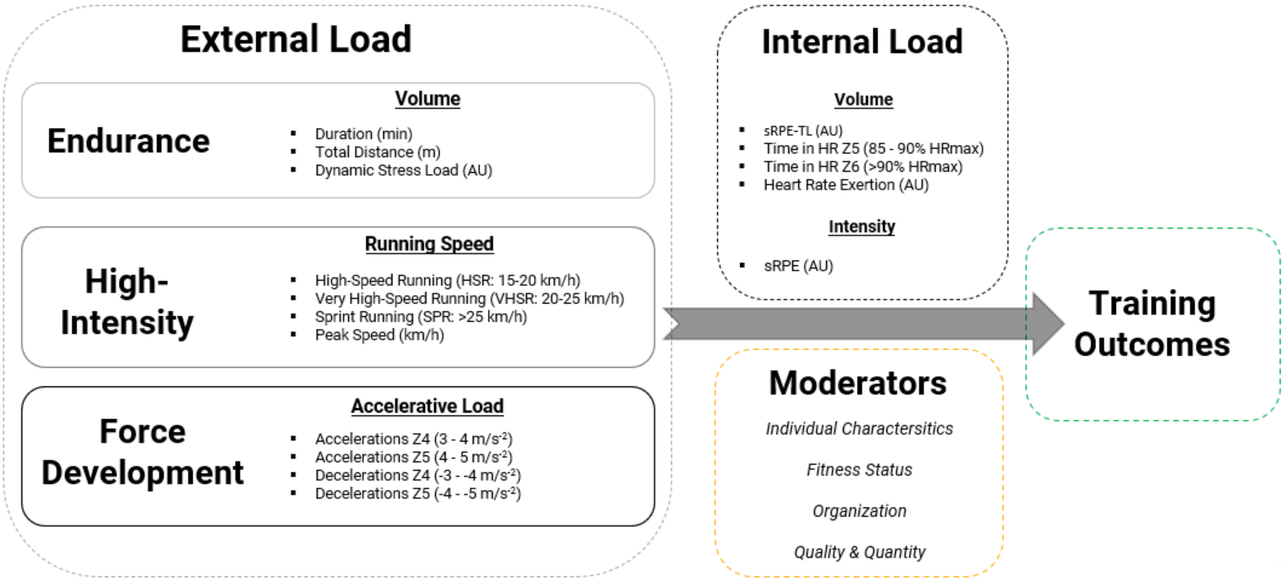


Figure 7.1. A conceptual framework for training load monitoring in elite youth soccer.

Before conducting the PCAs all variables were inspected for abnormal values caused by tracking errors and removed (range 0-11%). For the analysis, only full team training sessions and players who completed a competitive match were included. Individual top-up sessions and rehabilitation sessions (e.g., sessions with a total distance less than 1.5 km and duration less than 30 min) were removed. Outliers (+/- 3 SD) were removed from each age group's dataset to reduce their effects on the correlations upon which PCA is based and scaled (z = (x-u)/s). Bartlett's sphericity test and Kaiser-Meyer-Olkin (KMO) tests were examined to ensure the data was suitable for PCA [158]. A PCA analysis with Varimax rotation was utilized on the two seasons of data for each of the four age groups assessed. Factors were extracted when Eigen values were greater than 1. Retained variables were visually examined across the different age groups.

7.3 Results

The analysis included 6031, 5885, 6466, and 8270 individual training session/match observations recorded across the two competitive seasons by players from the U15 to U19 age groups, respectively. The components extracted by the absolute and relative PCA and the strength of loadings of the variables retained for each age group are presented in tables 7.2 and 7.3, respectively.

In the absolute PCA four components were extracted after rotation for U15, U16, and U19, while only three were extracted for U17. The components described 67.2%, 69.9%, and 72.7%, respectively across the three age groups including four components. In U17, the three components described a similar degree of variance (65.0%) due to a greater weighting of the first two. The relative PCA also identified four components after rotation for all four age groups, describing 64.7%, 67.4%, 70.4%, and 71.0%, respectively for U15 to U19.

Across the four different age groups, the absolute PCA consistently retained 14 variables, while the relative PCA consistently retained 13. In general, the components were related to the volume of load, ACC load, the quantity of high-speed running, and HR load. The variance of load described was evenly spread across the four components, ranging from 12.0 – 22.8% for both the absolute and relative PCA. However, inconsistencies were observed in the order in which the variables load and the strength of loadings across the four different age groups. The order in which variables load also differed slightly between absolute PCA and relative PCA, despite similar constructs of load emerging. For example, sRPE loaded with different measures of internal and external load, in the first or second component of the absolute PCA, while it appears to describe a distinct construct in the relative PCA. Dynamic Stress Load loaded inconsistently in the absolute PCA and did not load in any age group in the relative PCA. Total time was the only other variable to load inconsistently in the absolute PCA.

Table 7.2. Absolute PCA component loadings by age group.

Age Group	**Under 15**				**Under 16**				**Under 17**				**Under 19**			
Component	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Variance Explained (%)	**18.8**	**18.2**	**16.4**	**13.7**	**22.8**	**21.1**	**14.0**	**12.0**	**29.3**	**21.9**	**13.8**	**-**	**22.3**	**19.9**	**15.7**	**14.8**
Total Time					0.59								0.51			
Total Distance		0.53			0.56	0.57			0.73				0.64			
Dynamic Stress Load					0.51								0.59			
HSR		0.71					0.76		0.62				0.64			
VHSR		0.53		0.56			0.76		0.51		0.53		0.50			0.60
SPR				0.88				0.89			0.89					0.86
Maximum Speed				0.90				0.90			0.88					0.85
Accel Z4	0.81				0.83					0.85				0.82		
Accel Z5	0.65				0.62					0.74				0.80		
Decel Z4	0.83				0.85					0.80				0.76		
Decel Z5	0.74				0.77					0.77				0.70		
Heart Rate Exertion			0.87			0.88			0.84						0.86	
Time in Hr Z5			0.78			0.76			0.72						0.72	
Time in Hr Z6			0.77			0.78			0.76						0.85	
RPE		0.81				0.60			0.75				0.82			
sRPE		0.84				0.55	0.58		0.73				0.83			

HSR – High-speed running (15-20 km/h), VHSR – Very high-speed running (20-25 km/h), SPR – Sprint running (>25 km/h), Z – zone, Accel - number of accelerations, Decel – number of decelerations, Hr – Heart rate, RPE – rating of perceived exertion, sRPE – session rating of perceived exertion.

Table 7.3. Relative PCA component loadings by age group.

Age Group	Under 15				Under 16				Under 17				Under 19			
Component	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Variance Explained (%)	**17.9**	**16.9**	**16.1**	**13.8**	**19.7**	**19.4**	**15.5**	**12.8**	**20.9**	**19.1**	**16.6**	**13.9**	**19.3**	**18.7**	**17.8**	**15.3**
Distance per min			0.60		0.59						0.53				0.55	
Dynamic Stress Load/min																
HSR/min			0.72				0.77				0.64				0.72	
VHSR/min			0.83				0.87				0.83				0.83	
SPR/min			0.63				0.54				0.72				0.77	
Accel Z4/min		0.80				0.84			0.85				0.82			
Accel Z5/min		0.64				0.62			0.69				0.79			
Decel Z4/min		0.81				0.82			0.81				0.77			
Decel Z5/min		0.75				0.77			0.77				0.72			
Heart Rate Exertion/min	0.90				0.88					0.89				0.90		
Time in Hr Z5/min	0.77				0.77					0.75				0.75		
Time in Hr Z6/min	0.80				0.77					0.81				0.83		
RPE/min				0.86				0.85				0.86				0.85
sRPE/min				0.90				0.91				0.92				0.88

min – minutes, HSR – High-speed running (15-20 km/h), VHSR – Very high-speed running (20-25 km/h), SPR – Sprint running (>25 km/h), Z – zone, Accel - number of accelerations, Decel – number of decelerations, Hr – Heart rate, RPE – rating of perceived exertion, sRPE – session rating of perceived exertion.

7.4 Discussion

The present study aimed to apply a conceptual framework to guide the selection of load variables included in a data reduction analysis. This approach was undertaken to determine if a guided approach to a PCA could provide an output that can be practically applied within an elite youth football player monitoring program. Identifying a reduced number of key training load metrics, based on the amount of variance they explain, should be included in the daily load monitoring process. We also assessed the consistency of the specific variables retained in the PCAs across the different age groups (U15-U19) to verify if a one-size fits all approach was feasible for a whole academy approach or if different variables contributed more variance across the four different age groups. The main results revealed that variance was described by four components in three of the age groups (U15, U16, and U19), with only three components explaining variance in U17. The components contained distinct themes that were consistent across each of the age groups assessed. The variance of load described by each component was also similar across the components identified in each age group, indicating that a myriad of factors is required to explain the training and match loads experienced by elite youth football players. However, there were differences in the order in which these components loaded between the age groups and the weighting of variables within each age group. Collectively, the present findings demonstrate that a one-size fits all approach does not result from data reduction methods of training load variables in an elite soccer academy, even when variable selection is guided by a conceptual framework.

The variance described by the components identified through the PCA ranges from 64–71%. These observations are in line with previous findings that have utilized PCA in team sports [187] and the few studies that have employed this method to aid the selection of external load variables [61, 192, 194]. Including fewer variables in the analysis makes it easier to describe more variance in fewer components [187]. In the present study, the total variation explained is distributed across the different components, with no clear "winner" describing the largest degree of variance (PC ranging from 18.8 to 29.3%). This contrasts with previous studies, where the first PC captured the most information (39-76%) [61, 190]. Furthermore, the small but progressive increase in variance described between U15 and U19 indicate that the relationship between load variables and the amount of variance they describe is not consistent between the groups. These subtle differences in the relationships between load variables also contribute to the disparity in the number of components retained from the analysis. Collectively, these findings suggest that the relationships between different load variables, and the structure of the load data recorded, may be influenced by differences in the nature of training and matches performed [64].

The current analysis revealed general themes that emerge in the components retained for each age group by the PCA. The general themes of the components in each age group, relate to 1) the total volume of load performed, 2) the ACC load, 3) the quantity of HSR and 4) the HR load. The only difference observed between the age groups was recorded in the U17, where the HR load loaded alongside variables relating to the total distance. The present observations support the inclusion of different constructs of load (i.e., external & internal) and different aspects of load (i.e., volume and intensity) in a youth football player monitoring system. Specifically, the present observations support the retention of total distance and high-speed running variables, which agrees with previous studies that demonstrated these metrics to describe the greatest degree of variance and are retained in the first components [190, 194]. Moreover, the observation of including ACC load in a load monitoring system also supports previous research on elite-level football players that identified this variable to contribute additional information [194]. However, this is not consistent in literature as ACC metrics have also been found to load alongside total distance and high-speed [190]. In the present study, the division of external load variables into three separate components (i.e., TD, VHSR, and ACC load) highlights the complex nature of load monitoring and that the use of a single variable will not sufficiently describe the nature of the load experienced by players.

A novelty of this study was the inclusion of internal load variables in the PCA. It is therefore noteworthy that HR-related variables were systematically retained across all four age groups. There were however differences in the contribution of this element between the age groups (ranging from first to the third component). In three of the age groups (i.e., U15, U16, and U19) HR variables loaded as a separate component, indicating that it contributes directly to describing additional variance in the wide array of training load variables recorded. Interestingly, despite being a measure of internal load [27] and previous reports of large correlations [203], sRPE and sRPE-training load variables did not load alongside HR in the present study. In elite youth Scottish players sRPE was reported to relate with all measures of external load [61], while it appears to be most related to total distance and quantity of high-speed running performed in this specific cohort. This is in agreement with previous findings [204] and appears to indicate that there is a differentiation in variables that relate to volume and intensity measures. These findings suggest that the quantification of the physiological stress being induced by external load provides additional information that ought to be considered during the training planning phase.

In the present study, limited differences were observed between the absolute and relative PCA outcomes. Notably, the first three components retained across all four age groups included similar variables, relating to ACC load, HSR, and HR load. Furthermore, the variance described was found to be stable between the first three components (16.1-20.9%), reinforcing the importance of these constructs identified [33] and their inclusion in a player monitoring program for youth soccer players. The main difference between the absolute and relative PCA results relates to the loading of sRPE as a separate component. This further confirms that sRPE is different from HR variables and suggests that the player's subjective measure of load provides additional information (12.8-15.3%) than objective measures provided by microtechnology. However, the relationship with sRPE was found to be consistently lower when expressed as a relative measure (i.e. divided by time) in elite Scottish youth players [195]. Collectively, these results indicate that practitioners could select to apply either of the two methods (i.e., total volume or volume expressed per minute) within their club, maintaining the same constructs of load identified in the present study.

Interestingly, the data reduction analysis applied in this study did not help to further reduce the number of variables identified through the conceptual framework. However, the identification of common themes in the PCA outcomes, in line with those included in the conceptual framework, can facilitate the selection of variables from within these constructs. This finding has important implications for the interpretation of the PCA results (whether selecting one key variable from each component or the aggregated construct score [159]) and simplifying the approach to data reduction. Collectively, these findings indicate that a mathematical data reduction analysis may not be suitable to simply identify the load metrics for a whole academy approach. However, a similar approach would have to be applied with alternative data reduction mathematical methods (e.g., factor analysis) to verify if the outputs can provide greater insights and a practical solution to which load variables to assess across an elite academy monitoring system.

Differences in the quantity and selection of variables utilized to date make between studies comparisons difficult [26, 187]. Future studies should consider evaluating how the inclusion of metrics based on individualized thresholds can impact upon the relationships between variables and influence the outcomes of the PCA. In a youth academy environment, the inclusion of relative thresholds could aid the assessment of training load variables within a specific age group and potentially reduce differences between age groups. A limitation of the present study is the inclusion of both training and match data in the analysis when significant differences have been observed across a weekly micro-cycle [61]. However, this choice was made to identify a set of load variables that could be included in the monitoring program and account for all sessions.

While the order of the four components identified by the PCA differed slightly between the four age groups, the general themes observed can aid practitioners by identifying distinct factors that should be incorporated in load monitoring in youth soccer. In general, practitioners should focus on controlling TD, HSR, ACC load, and HR load. These findings support that no one main factor or variable can be utilized to describe all the variance in the load being recorded and the inclusion of both external and internal load [75] in any load monitoring program. The specific load variables identified through the guided PCA align closely with the themes identified by the conceptual framework for inclusion in the PCA. The advantage of utilizing this approach, and the agreement with variables retained, ensures that the metrics are readily monitored by practitioners and can facilitate the interpretation of training load outcomes for practical applications on the pitch. Utilizing established conceptual models and the expertise of experienced practitioners can help to effectively guide the reduction of load variables included in a player monitoring program.

CHAPTER EIGHT

Study Seven: Assessment of dose-response relationships between 1-week and 4-week cumulative training load and physical performance outcomes in elite youth soccer

Chapter preface

This study evaluated the relationships between the acute (1 week) and chronic (4 weeks) training load performed by youth soccer players and their changes in fitness outcomes. This builds on the limitations identified in literature during the systematic review, including metrics relating to both internal and external load and their association with different elements of physical fitness (i.e., aerobic, intermittent, and power aspects). The results provide a unique insight into the timing of changes in fitness levels across a competitive season and differences in the levels recorded between different age groups. The findings allude to the multifactorial nature of these relationships, impacted by periodization of load and changes in youth players maturation. Limited relationships were recorded with chronic load appearing to exert a greater influence on test outcomes, suggesting practitioners should also consider this aspect when planning the next training micro- or mesocycle.

8.1 Introduction

Soccer is a team sport that requires players to perform prolonged high-intensity intermittent exercise and numerous intense actions, eliciting a high level of force production, during a match [8, 63]. The stochastic nature of the game, changing activity every 5 seconds, stresses a wide range of different physical capabilities [10, 63]. The physiological determinants of soccer performance have previously been described [8, 63] and highlight the importance of aerobic fitness, ability to repeatedly perform high-intensity actions and muscular strength. The focus on adaptive responses to training has increased following the association between physical fitness levels and positive outcomes relating to soccer performance [174, 205, 206], ability to recover quicker between high-intensity efforts [207] and reduced injury risk [199, 208].

It is common practice for elite-level football clubs and their youth academies to carry out periodical physiological assessments to systematically monitor longitudinal adaptations to the training and match load undertaken. The evaluation of fitness and monitoring of the development of physical capabilities is important in elite youth soccer, as such information helps inform on best strategies to prepare players for the increased loads they are exposed to as they progress through the youth academy [29, 65, 84]. To facilitate testing across the competitive season, and its integration into the training plan, submaximal evaluations tend to be preferred to maximal efforts as they are both more time efficient and less influenced by the players motivation levels [22, 45]. Practitioners tend to utilize a combination of different tests to assess diverse physiological aspects and objectively measure athletes' current physical condition [57, 102, 209].

The recent development of a conceptual framework has helped to further highlight the relationships that exist between training load and fitness responses [62, 75, 119]. In general, performance outcomes are mediated by the combination of positive and negative responses induced by training [62, 119] and can be influenced by the manipulation of training frequency, intensity, duration, mode and distribution [20]. One theoretical framework that describes the training process, now widely applied across numerous sports, separated training load into two distinct categories: external and internal load [75]. Where external load refers to the quantity and intensity of load performed by each player (e.g., total distance, high-speed running, number of ACC etc.) and internal load refers to the psycho-physiological stress mediated by the external load (e.g., HR intensity and rating or perceive exertion) [75]. The use of wearable technologies (e.g., GPS systems) has greatly facilitated this process by allowing practitioners to quantify the volume and intensity of load performed during training and matches by each individual player [23, 26].

The improved ability to accurately quantify the training loads performed has however led to an issue relating to the selection of variables to retain in a player monitoring programme and inform decisions relating to training prescription [185, 188]. Determining the training load variables have the greatest impact on training-induced changes on diverse aspects of physical fitness and performance characteristics (e.g., aerobic capacity, high-intensity intermittent efforts, and muscular power characteristics) can significantly aid the training prescription process, facilitating players achieving predetermined physical objectives within sport-specific tactical training sessions. This can be referred to as a dose-response relationship [58].

Another aspect relating to training load that has received a great amount of attention in numerous team sports is the accumulation of load over different times frames and the impact of its distribution on physical fitness outcomes and injury risk [81, 210, 211]. This aspect has recently been emphasized by a conceptual framework that suggested that positive or negative acute and chronic training effects can be induced by the levels of training load recorded [62]. However, this approach has yet to be applied to the analysis of dose-response relationships. Most studies performed to date have assessed the amount of load recorded in specific periods of a competitive season (ranging from 1 week to an entire season) [60, 212]. Establishing the impact of loads accrued 1 week and 4 weeks prior to a test session can shed light on the influence of different load variables on physical fitness outcomes in youth soccer player, ultimately aiding the training prescription process.

Furthering our knowledge relating to the acute and chronic effects of training load [62] can inform decisions regarding the future training plan and the implementation of individualized interventions [130]. To date, several studies have investigated associations between training load and changes in players physical fitness measures, including a wide range of different training load measures (both internal and external) and physical assessments [58]. These studies have, however, demonstrated inconsistent and unclear relationships between different constructs of training load (i.e., training exposure, sRPE training load, HRE and players external load) with changes in aerobic fitness and intermittent performance in youth soccer [60, 90, 138, 213-215]. Relationships between training load measures and neuromuscular capacity have also previously been assessed [96, 98, 213, 214], however, the lack of standardisation in the test methods utilized to assess neuromuscular quality between the studies makes comparisons difficult. Additional concurrent factors, including players trainability, recovery status, type of stimulus players are exposed too can potentially influence the relationships recorded. Furthermore, the period of the season assessed within studies appears to influence the strength of the relationships, with the preseason period showing the largest changes in aerobic and intermittent running ability and no other significant improvements observed across the competitive season [102]. In general, the combination of all these factors that can influence a dose-response relationship may impact upon the establishment of a linear relationship between training load and changes in youth players physical fitness.

At present, little evidence is available relating to associations between load variables on different aspects of fitness or how the strength of these relationships varies across the different age groups. In addition, the studies conducted to date tend to focus on a specific period of the competitive season and include small sample sizes [102]. Therefore, this study aimed to evaluate the dose-response relationships between select internal and external training load variables recorded over the acute (1-week) and chronic (4-week) periods with changes in physical fitness in elite youth soccer players.

8.2 Methods

Study design

A retrospective observational design was employed to assess the relationship between training loads performed and variations in elite youth player physical fitness outcomes across 5 competitive seasons (2017-18 season to 2021-22). The three age groups included in the analysis (U16, U17 and U19) all perform the same standardized battery of physical evaluations at fixed time points across the competitive season, further standardized as always being performed following a day of rest with no training. Internal and external training loads were recorded during every training session and match, with the load accumulated over fixed periods (1- to 4- weeks at the beginning, middle and end of the competitive season) quantified to determine how variations in levels influence players physical fitness. This process involved players performing three different fitness tests, aimed at assessing different aspects related to soccer performance, four times a season. Linear mixed models were applied to determine associations between six load variables, across two different time frames (1- and 4-week), and changes in test outcome measures.

Participants

Elite youth soccer players belonging to the U16 to U19 squads of the same academy participated in this study. Players monitored during 5 competitive seasons (2017-18 to 2021-22) were grouped according to their age category, with a new squad of players monitored in each age category, each season. For the analysis, only players that completed two consecutive test sessions and had a complete training load dataset for the month before the second assessment were included. In the final analysis, 102 elite youth soccer players were included, their anthropometric measures are presented in Table 8.1. Written informed consent was collected from each subject and their legal guardian before the commencement of the study. The study was approved by the University Research Ethics Committee (UTS HREC ETH19-4420).

Table 8.1. Descriptive of included player's anthropometric measurements (mean ± SD).

	Under 16	**Under 17**	**Under 19**
n	55	42	29
Age (y)	15.4 ± 0.2	16.4 ± 0.3	17.9 ± 0.5
Height (cm)	175.0 ± 5.6	178.1 ± 5.2	181.4 ± 5.9
Weight (kg)	64.1 ± 6.8	69.0 ± 5.6	73.4 ± 5.8

Procedures

Training Load Measures

The internal and external training loads completed by each individual player were monitored across the entire observation period utilizing HR monitors (Polar Team2 system, Polar Electro, OY, Finland) and a GPS sampling at 10 Hz (APEX, Statsports, Ireland). HR measures were expressed a percentage of the highest value recorded (HRpeak) during the competitive season (i.e., recorded during matches or maximal fitness tests)) and reported as time spent in specific intensity zones. The GPS devices, previously reported to be valid and reliable for team sports [191], were activated at least 15 minutes prior to each training session or match and placed in a custom-made pocket between the players scapulae of a tight-fitting vest. Each player was assigned their own GPS unit at the beginning of the season to improve data quality and reduce issues related to inter-unit reliability [176]. All activities, from the beginning of warm-up to the end of each session were quantified (including stoppages, the transition between drills, etc.). The data collected during every session was downloaded utilizing the manufacturer's software (APEX, Statsports, Ireland) before being stored in a custom-built in-house software.

Each player's sRPE was recorded manually ~30 minutes following the end of every training session and match performed using the CR-10 Borg scale [79, 134]. This was collected by the teams' sport scientist on a one-to-one basis inviting players to carefully look at the scale and verbal anchors before providing their rating. Before commencing the study all players were familiarized with the validated Italian translation of the Borg Scale [25], and this familiarization process was repeated at the beginning of each competitive season. The sRPE-training load for each session was subsequently calculated by multiplying the players sRPE by the duration of the session [79].

In-season training data recorded before the three testing sessions were utilized for the analysis. The battery of tests is performed as a baseline in the first days of preseason training (PRE), at the beginning of the competitive season (IN1), halfway through the competitive season (IN2) and before the final stage and play-offs (IN3). As the present study we conducted over 5 competitive seasons it is important to specify that the time periods beginning of preseason always occurred in the same period of the calendar year and the time between test sessions was similar, in accordance with the playing calendar (e.g., IN1 = week 6 – 10, IN2 = week 18 – 22, IN3 = 36 – 40). The cumulative load recorded across 1-week and 4-week periods (i.e., the sum of load data performed across the different days of a weekly micro-cycle) was utilized for the analysis. The inclusion criteria relating to training load data was the availability of 4 full weeks of training load, including all training and matches, before the subsequent test session. Players with missing data due to injury, national team commitments or other absences were excluded. For the analysis, the following variables were selected to quantify load: TD, VHSR (distance >20 km/h), ACC (n $>3 \mathrm{m \cdot s^{-2}}$), HR between 85-90% HRmax and above 90% HRmax (HR85-90% and HR90%, respectively) and sRPE-TL.

Physical Evaluations

In addition to their regular training program, the youth soccer players were also required to perform a battery of physical tests 4 times across the competitive season (pre-season as a baseline measure, beginning, middle and end of the regular season). The testing protocols aimed to assess different components of their fitness characteristics (i.e., aerobic, intermittent or power)[63]. The physical fitness evaluations selected for this study were based on their practical applicability, being pitch-based and sub-maximal to facilitate their prescription and be repeated during the competitive season without incurring any negative side-effects or issues with technical training. The submaximal nature of the evaluations utilized allows for continuity across the different age groups as younger players perform the same test protocols as their older counterparts. To standardize the testing conditions, they were always performed following a rest day. The tests were performed in the sequence of Mognoni Test, vertical CMJ and HIT running test. No warm-up protocol was performed prior to the first submaximal running test, while a standardized 5-minute warm-up protocol was performed prior to the two subsequent evaluations. All participants were familiarized with the testing procedures before performing the evaluations and the practitioners conducting the tests remained the same across the entire studies timeframe.

The Mognoni Test, an assessment of aerobic fitness in soccer players, consists of a 6-minute continuous running protocol performed at a constant speed of 13.5 km/h [22, 102]. The test is carried out on a 300-meter track set up on the football pitch with an acoustic signal pacing the players running speed at 50 m intervals. Players perform no warm-up before commencing the test to avoid any confounding effects on the physiological responses to the test. Immediately after completing the test, a capillary blood sample was taken from the earlobe of each player to ascertain their level of blood lactate accumulation. The measurement was performed using two portable micro-volume lactate analysers (Lactate plus, Nova Medical, USA) with the mean of the two values recorded retained for the analysis. An internal validation recorded reliability of these measures similar to those reported by Martin et al. (coefficient of variation of 7.8% vs. 8.0% in literature) [102].

The players also performed a series of vertical CMJ performed on portable force platforms (ForceDecks FDLite, Vald Performance, Australia) recording at a sampling rate of 1000 Hz. All players completed a standardized warm-up prior to performing five single CMJs. The CMJs were conducted with players starting in a stationary standing position, with feet placed shoulder width apart and hands akimbo. The depth of the countermovement was self-selected by the players; however, the jump technique was assessed to ensure valid execution of each jump (i.e., jumps were not counted if the players removed their hands from their hips or flexed their knees during the jump). The data relating to each jump was calculated by the force platform software (add details) and imported into a custom-built in-house software. For this study, only the mean of the three best absolute peak power outputs was considered for data analysis. This procedure has previously been shown to have good reliability [216].

The players also completed a High Intensity Intermittent running (HIT) Test [102, 206], consisting of 10x10 second shuttle-runs over 25 m, performed at 18 km/h with 20 seconds of recovery between each bout. Like the Mognoni test, acoustic signals and reference cones located on the field were utilized to pace players running speed. Upon completion of the 5-minute protocol players blood lactate accumulation was again evaluated from a capillary bloody sample taken from the players earlobe, utilizing the same instruments and procedure described for the Mognoni test.

Statistics

Two different analyses were conducted to investigate 1) the difference between age groups and phase of the season and 2) the relationship between levels of load recorded and physical outcomes.

For the first analysis, we conducted a two-way repeated measures analysis of variance (ANOVA) to investigate differences between test period and age groups in the results of the three physical evaluations (Mognoni, HIT and CMJ) and each of the training load variables included. Pairwise comparisons using Tukey's Post Hoc test with 95% CI were computed.

For the second analysis, we applied a linear mixed-effect model to determine which internal or external load variables are associated with positive or negative variations in players' physical condition. This approach accounts for pseudoreplication, missing data and allows for a mixture of both fixed and random effects [217]. The results of the three different physical evaluations were utilized to calculate the absolute change in fitness recorded with respect to the previous test session. To establish the relationship with load the cumulative load recorded 1-week and 4-weeks before each test session was calculated for each of the 6 variables included.

Three separate 3-level linear mixed models were utilized to examine associations between the training load variables and changes in players physical fitness across three different age groups of the elite youth academy (i.e., one for each test outcome). The fixed and random effects utilized in this study are presented in Table 8.2.

Table 8.2. Covariates included in the model specification for outcome measures.

Data Level		Factors	Type	Classification
Level 3	Clusters of Clusters (random factor)	Age Group (U16, U17, U19)		
Level 2	Cluster of units (random factor)	Player		
Level 1	Unit of Analysis	Individual season samples		
	Dependent variable	Mognoni Test Change	Continuous	mmol/L
		HIT Test Change	Continuous	mmol/L
		CMJ Measure Change	Continuous	Watt
	Covariates	Accumulated TD (1-week)	Continuous	m
		Accumulated VHSR (1-week)	Continuous	m
		Accumulated ACC (1-week)	Continuous	n
		Accumulated HR85-90% (1-week)	Continuous	min
		Accumulated HR>90% (1-week)	Continuous	min
		Accumulated sRPE-TL (1-week)	Continuous	AU
		Accumulated TD (4-week)	Continuous	m
		Accumulated VHSR (4-week)	Continuous	m
		Accumulated ACC (4-week)	Continuous	n
		Accumulated HR85-90% (4-week)	Continuous	min
		Accumulated HR>90% (4-week)	Continuous	min
		Accumulated sRPE-TL (4-week)	Continuous	AU

HIT, High-intensity intermittent running test; CMJ, Countermovement jump test; TD, Total distance; VHSR, distance covered above 20 km/h; ACC, number of accelerations recorded above 3 $m \cdot s^{-2}$; HR85-90%, time spent between 85% and 90% of heart rate peak; HR90% time spent above 90% of heart rate peak; sRPE-TL, session rating of perceived exertion; mmol/L, Millimoles per litre of blood lactate accumulated; m, metres; n, number; AU, arbitrary units; min, minutes.

A "step up" approach was utilized for model construction to determine the influence of random factors on the dependent variables. This process involves the construction of an unconditional model, containing only a fixed intercept and two random factors, to establish if variation existed in the dependent variable. This step involved the visual comparison of the Akaike information criterion (AIC) to identify the best fit model, where a lower AIC represents the better model fit. The models were then evaluated again following the addition of level 1 fixed effects, followed by level 2 and level 3 fixed effects. The single fixed effects were retained if it was found to significantly improve the model and its fit (i.e., improving AIC) compared to the previous model. This approach has previously been utilized in soccer and other team sports [102, 217].

The linear mixed models *t* statistic and degrees of freedom (*df*) were calculated and then converted to get an effect size correlation (*d*) between each factor and associated 95% CI on the dependent variable [217, 218]. The threshold values utilized for the interpretation of Cohen's d were as follows: <0.20, trivial; 0.20–0.59, small; 0.60–1.19, moderate; 1.20–1.99, large; >2.00, very large [135]. Statistical significance was set at $p < 0.05$. Statistical analysis was conducted in R statistical software (version 3.6.3) (R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2019).

8.3 Results

Over the five competitive seasons, 283 Mognoni tests, 282 HIT tests and 279 CMJ test observations were collected from 102 individual players that had completed the previous test session and had full training and match load data available for the 4-weeks before the assessment. The number of the individual physical fitness tests assessed in each test session was 111, 106 and 65 at IN1, IN2 and IN3, respectively.

The distribution of mean test results for the three age groups and test periods are presented in Figure 8.1, with Pairwise comparisons presented in Table 8.3. Mognoni, HIT and CMJ were all found to have a significant effect for category and period ($p < 0.002$). In both the Mognoni and HIT, the U19 and U17 were found to have a significantly lower blood lactate accumulation than U16 ($p < 0.009$), with no significant difference between these two older age groups ($p > 0.28$). CMJ power measures were significantly different between each of the three age groups ($p < 0.0002$). For Mognoni, IN1 and IN2 blood lactate values were significantly lower than PRE ($p < 0.002$) with no significant changes observed across the in-season test periods. HIT also demonstrated a significant reduction in blood lactate accumulation from PRE to all IN test periods and no significant difference for IN test periods. CMJ did not record a significant change in measures between PRE and IN1 ($p = 0.63$) but there were increases in power between PRE and IN2 and IN3, respectively ($p < 0.025$). No significant increases in CMJ power were recorded between PRE and IN1 ($p = 0.63$). CMJ power did however improve significantly across the in-season periods, both from PRE to IN2 and IN3 ($p = 0.022$ and $p = 0.0009$) and from IN1 (IN3 > IN1, $p = 0.05$).

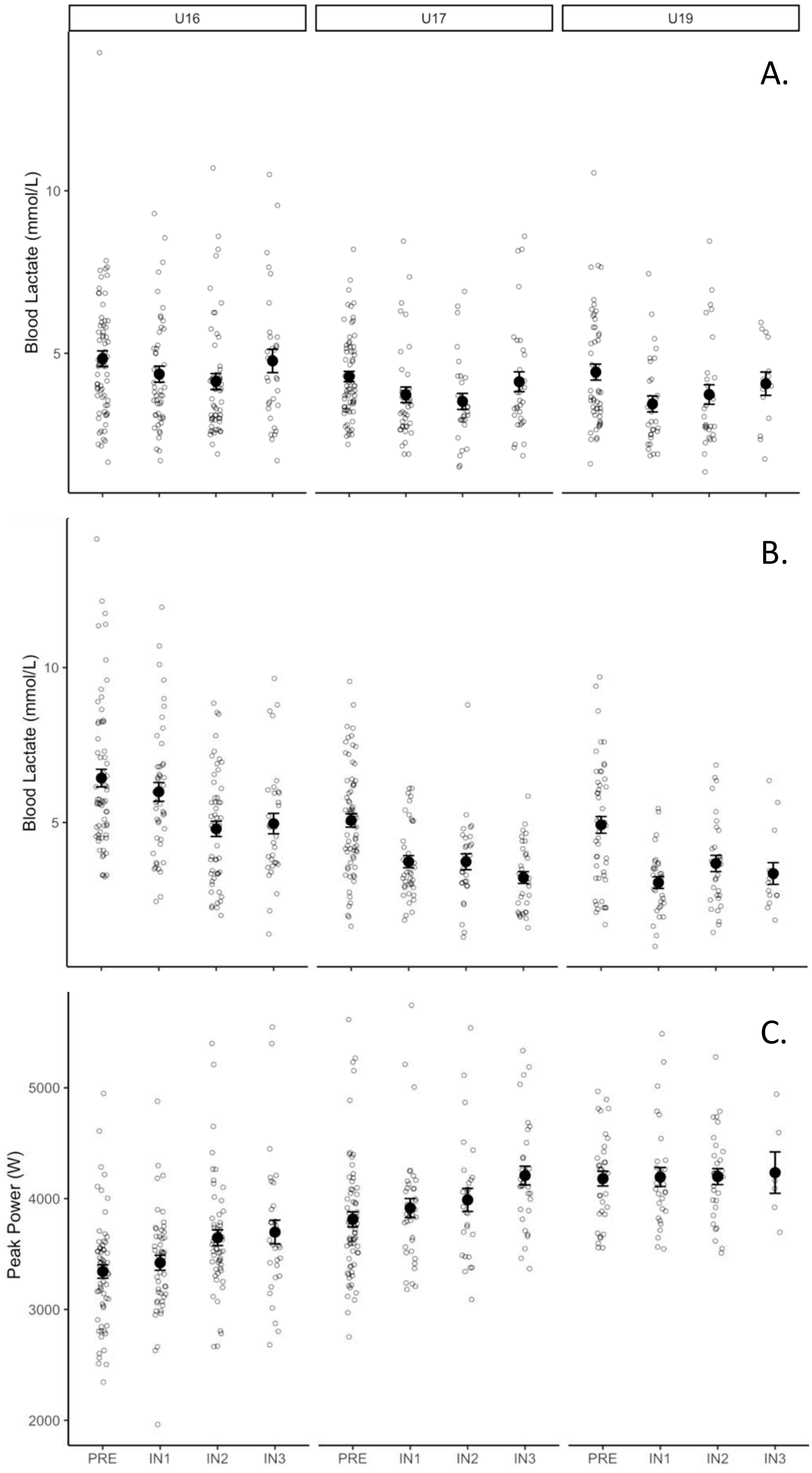


Figure 8.1. Distribution of test results across team categories and test periods. A, Mognoni blood lactate concentration; B, HIT blood lactate concentration; C, CMJ peak power values.

mmol/L, millimoles per litre of blood lactate concentration; W, Watts; PRE, preseason baseline evaluation; IN1, first in-season evaluation; IN2, second in season evaluation, IN3, third in-season evaluation.

Table 8.3. Pairwise comparisons using Tukey's post hoc test with 95% confidence intervals across team categories and across test periods.

	MOGNONI				**HIT**				**CMJ**			
	Delta	**95% CI**			**Delta**	**95% CI**			**Delta**	**95% CI**		
	Δ	**lwr**	**upr**	***p***	**Δ**	**lwr**	**upr**	***p***	**Δ**	**lwr**	**upr**	***p***
Differences across age groups												
U17-U16	-0.59	-1.00	-0.18	0.002	-1.56	-2.00	-1.12	<0.001	453	329	577	<0.001
U19-U16	-0.57	-1.01	-0.12	0.008	-1.76	-2.24	-1.29	<0.001	711	568	854	<0.001
U19-U17	0.03	-0.43	0.49	0.989	-0.20	-0.69	0.29	0.5982	259	110	407	0.001
Differences across test periods												
PRE-IN1	0.61	0.10	1.11	0.011	1.04	0.50	1.58	<0.001	-72	-228	84	0.630
PRE-IN2	0.65	0.14	1.17	0.006	1.30	0.76	1.84	<0.001	-175	-333	-18	0.022
PRE-IN3	0.14	-0.44	0.72	0.922	1.55	0.94	2.17	<0.001	-269	-452	-86	0.0001
IN2-IN1	-0.05	-0.61	0.52	0.997	-0.26	-0.86	0.34	0.684	103	-68	274	0.408
IN3-IN1	0.47	-0.16	1.09	0.218	-0.51	-1.18	0.15	0.197	197	2	391	0.046
IN3-IN2	0.51	-0.12	1.14	0.153	-0.25	-0.92	0.42	0.766	94	-102	289	0.605

PRE, preseason baseline evaluation; IN1, first in-season evaluation; IN2, second in season evaluation; IN3, third in-season evaluation; HIT blood lactate concentration; C, CMJ peak power values; *p, p*-values adjusted for multiple comparisons; CI, confidence interval; lwr, lower limit; upr, upper limit.

Table 8.4 shows the mean cumulative training loads in the 1- and 4 weeks before the date of the test, stratified per age group and test period. The distribution of the 6 load variables load variables across team categories and test periods are presented in Figure 8.2. A significant effect for category and period was recorded for 1-week training load in five of the six variables assessed ($p < 0.021$), only HR85-90% was not influenced by category ($p = 0.257$). For the 4-week training load, TD and sRPE-TL were not significantly influenced by category ($p > 0.15$), while all were significantly influenced by period ($p < 0.0007$). With regards to the 1-week training load, there are significant reductions in load between IN1 to both IN2 and IN3 for TD, ACC, and sRPE-TL, with no significant change recorded between IN2 and IN3. The VHSR distance demonstrated similar progression, with a significant decrease between IN1 and IN3, but only a trend for reduced distance covered above this threshold between IN1 and IN2 ($p = 0.053$). The two HR thresholds showed differences in periodisation, with no change between IN1 and IN2 ($p > 0.11$), but a significant reduction between IN1 and IN3, and IN2 and IN3 ($p < 0.008$). For 4-week training load periods, there were significant reductions between IN1 to both IN2 and IN3 for TD, ACC, HR85-90% and sRPE-TL, with no significant change between IN2 and IN3. In contrast, VHSR demonstrated no significant change between IN1 and IN2, but IN3 was significantly lower than both IN1 and IN2. A significant difference in HR90% was observed between IN1 and IN3 (*p* = 0.027).

The construction of the model for assessing the associations between load and performance was optimized by including individual players as a random effect, indicating statistically significant variance between players across all three physical evaluations. The inclusion of team category as a second random factor was observed to further optimize the model, reducing residual variance for HIT and CMJ. However, this was not the case for Mognoni test, where no significant differences were recorded with the addition of team category (*p* = 0.2929).

The final model statistics and regression coefficients displayed no covariates (i.e., cumulative load variables over a 1- or 4-week period) have a significant association with change in Mognoni test results. For HIT a small significant positive association was found for HR90% recorded across 4-week period (*p* = 0.0155, *d* = 0.21). sRPE-TL 1-week before the test was also significant with a trivial effect size (*p* = 0.0317, *d* = -0.18). There is also a trend (*p* = 0.0547) for VHSR 4-week load to be associated with lower accumulated blood lactate in HIT. In CMJ, VHSR was also observed to have a small positive effect (P < 0.0003, *d* = 0.23) on test outcomes. sRPE-TL 1-week before the test was also significant for CMJ with a trivial effect size (*p* = 0.044, *d* = 0.17).

Table 8.4. Mean ± SD for load variables for 1- and 4-week periods across team categories and test periods.

Age Group	Test Period	Total Distance (m)	VHSR (m)	ACC (n)	HR 85-90% (min)	HR >90% (min)	sRPE TL (AU)
		1-week cumulative load					
U16	Overall	34473 ± 7769	1425 ± 632	308 ± 94	49 ± 23	33 ± 30	1728 ± 431
	IN1	37564 ± 7303	1569 ± 666	341 ± 77	55 ± 24	37 ± 32	1836 ± 394
	IN2	34344 ± 7603^{a}	1481 ± 585	311 ± 103	52 ± 22	41 ± 33	1816 ± 419
	IN3	30095 ± 6670^{a}	1120 ± 565	252 ± 76	34 ± 17	15 ± 12	1425 ± 364
U17	Overall	37310 ± 9766*	1755 ± 837*	357 ± 102*	51 ± 23	35 ± 28	1824 ± 642
	IN1	40238 ± 7207	2001 ± 727	396 ± 76	55 ± 23	38 ± 31	1995 ± 403
	IN2	34563 ± 13544	1617 ± 1048	330 ± 136	54 ± 26	39 ± 32	1494 ± 879
	IN3	36347 ± 7391	1589 ± 685	336 ± 77	45 ± 17	29 ± 22	1922 ± 511
U19	Overall	36701 ± 7525	1474 ± 586#	288 ± 91#	49 ± 25	27 ± 21#	1993 ± 670*
	IN1	37767 ± 6806	1583 ± 601	300 ± 103	58 ± 24	25 ± 19	2250 ± 627
	IN2	37427 ± 7124	1444 ± 534	288 ± 79	42 ± 22	30 ± 22	1805 ± 616
	IN3	28769 ± 8620	1121 ± 673	239 ± 82	37 ± 28	23 ± 22	1689 ± 772
		4-week cumulative load					
U16	Overall	144700 ± 23726	6360 ± 2360	1260 ± 290	210 ± 70	154 ± 124	7279 ± 1121
	IN1	158729 ± 20881	6568 ± 2512	1360 ± 258	243 ± 67	188 ± 148	7944 ± 819
	IN2	135534 ± 23102^{a}	6641 ± 2351	1232 ± 319	199 ± 69	153 ± 114	6971 ± 1201
	IN3	136879 ± 18185^{a}	5593 ± 2011	1154 ± 245	180 ± 58	104 ± 72	6749 ± 895
U17	Overall	144304 ± 20218	6962 ± 2052	1345 ± 236	207 ± 67	132 ± 79	7507 ± 1509
	IN1	153840 ± 17643	7631 ± 1708	1440 ± 227	227 ± 73	142 ± 85	8268 ± 1365
	IN2	139295 ± 23109	6612 ± 2394	1303 ± 244	210 ± 57	139 ± 80	6945 ± 1666
	IN3	137393 ± 15592	6474 ± 1919	1269 ± 203	179 ± 62	114 ± 71	7117 ± 1109
U19	Overall	139443 ± 31627	6017 ± 2125$^{\#}$	1079 ± 365$^{*\#}$	176 ± 89$^{*\#}$	110 ± 94*	7606 ± 1714
	IN1	153369 ± 33685	6102 ± 2100	1185 ± 430	213 ± 100	93 ± 104	8323 ± 1276
	IN2	139363 ± 20836	6506 ± 2137	1086 ± 245	159 ± 78	126 ± 94	7491 ± 1555
	IN3	109608 ± 25043	4854 ± 1843	835 ± 316	132 ± 53	115 ± 68	6293 ± 2091

VHSR, distance covered above 20 km/h; ACC, number of accelerations recorded above 3 m.s^{-2}; HR85-90%, time spent between 85% and 90% of heart rate peak; HR90%, time spent above 90% of heart rate peak; sRPE-TL, session rating of perceived exertion; m, metres; n, number; min, minutes; AU, arbitrary units; IN1, first in-season evaluation; IN2, secondo in season evaluation, IN3, third in-season evaluation. a - significantly different to IN1; b – significantly different to IN2; c - significantly different to IN3; * - significantly different to U16; # - significantly different to U17; § - significantly different to U19.

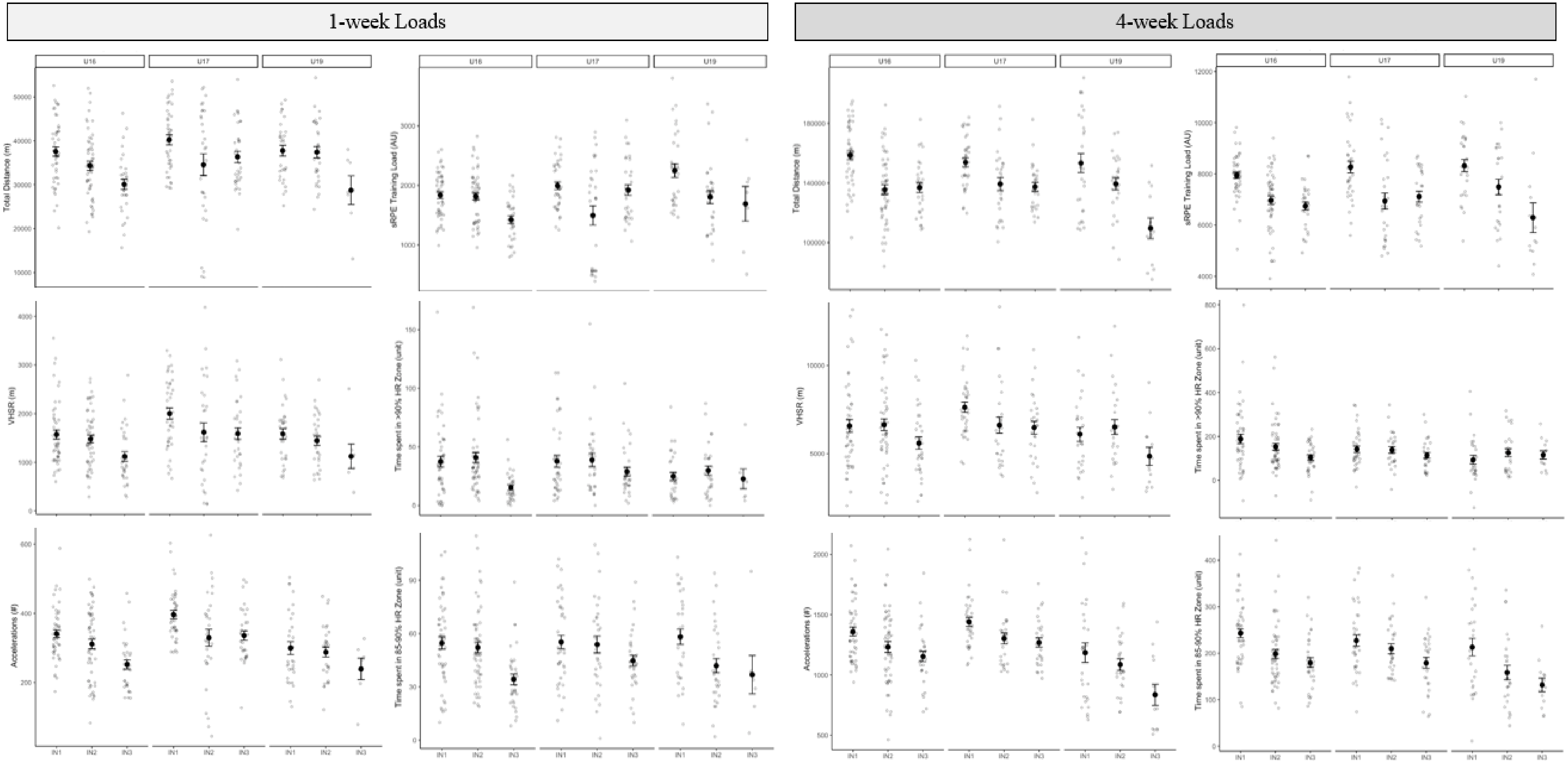


Figure 8.2. Distribution of load variables across team categories and test periods. VHSR – Very high-speed running, sRPE – session-rating of perceived exertion, HR – heart rate.

8.4 Discussion

The present study aimed to assess the dose-response relationship between select training load variables and changes in youth soccer player's physical capacity. The main findings show that aerobic and intermittent running capacity improves in the preseason, whilst muscular performance increases in the later part of the season. These improvements in test outcomes also appear to be related to the periodization of load across the competitive season, where a general reduction in the levels of training load was observed following preseason, with a distinct modulation of different constructs of training load. This longitudinal approach, across a season and different age groups, provides an insight into the progression of youth soccer players physical capacity across different physiological assessments. The association between internal and external training load measures and changes in physical fitness also appear to be related to specific fitness variables and influenced differently by the acute and chronic training load.

Aerobic and high-intensity intermittent running capacity were both increased during the preseason period. These observations align with previous studies conducted on elite Scottish youth players [117], semi-professional and elite adult players [102, 214, 219, 220]. The changes in the fitness variables have been attributed to the higher levels of training load typical of the preseason [102] and greater emphasis of training prescription (i.e., specific activities) aimed at developing endurance capacity during this period [220]. The effect of offseason detraining may also help explain why the magnitude of changes in these fitness characteristics are larger during preseason training (i.e., detraining in the offseason followed by a large training stimulus) [221]. Like previous studies [35, 40, 102], the initial improvements in continuous and intermittent running capacity obtained in the preseason are then maintained throughout the competitive season, without ulterior improvements. However, it must also be noted that the number of physical tests retained from the last period of the season (i.e., IN3) were lower than the first two test periods included in the current analysis. This observation mainly relates to a number of different practical issues, for example: occurrence of injuries during the competitive season, elite level players called up to the National team, and players changing team (within the club or out of the club). The maintenance of physical fitness levels is likely due to a shift in the focus of training during the competitive period, focusing more attention to technical and tactical aspects, recording lower levels of training load (both external and internal) [102]. The improvements in physical fitness recorded during the preseason period allows practitioners to modulate and the periodization of in-season training to help ensure maintenance of fitness levels [222].

However, this observation of marked physical improvements in the first phase of the season appears to not be valid for all physical abilities that contribute to soccer performance [63]. In contrast to the Mognoni and HIT test results, the temporal changes in CMJ power measures did not occur during the preseason but increased progressively during the in-season periods. This finding is in line with previous studies on young professional soccer players that recorded negative correlations between larger training volumes and accumulated training load during the preseason on the development of explosive neuromuscular characteristics (i.e., CMJ height) [92]. Reduced CMJ performance has previously been reported in some studies examining periods of intensified training [223] or overreaching in soccer players [224]. This is also in agreement with previous observations that CMJ performance is sensitive to periods of intensified training, like preseason [223, 225]. These observations may also help to interpret the improvements in power values recorded following the lower in-season training loads. The accumulation of complementary strength training session across a competitive season may also contribute towards the observed improvements in players power output [226]. These observations are similar to those observed in an English Premier League club [96] that reported in-season training loads not to be sufficiently taxing to induce negative changes in CMJ performance. However, the in-season improvements in CMJ power are likely related changes in physical maturity [15] and the long-term benefits of systematic training and appropriate training loads [7, 116]. Indeed, the present findings showed that the players increased CMJ performances as the season progressed and in the older age groups (post-puberty).

Both the 1-week and 4-week training loads before test sessions were reduced in the in-season periods compared to the preseason. The reduction in training load during the in-season has likely explained the increase in training structure in-season (i.e., number of sessions and time available), as well as the greater emphasis on technical/tactical development compared to physical qualities and an increased focus on training load management to ensure players are recovered for the weekly matches [96, 98]. Indeed, different training methods or regimes and periods of the season may influence the dose-response relationship being elicited. Furthermore, in accordance with training theory, it must also be considered that changes in players physical variables may be impacted differently by the loads performed in short or longer periods of time. The training “dose” the players are being exposed to can impact upon their physical responses and adaptations [119]. Notably, the reduction in training load was not systematic across all variables assessed. For example, whilst most load variables (TD, ACC, HR 85-90% and sRPE) were higher in the preseason compared to the in-season periods, VHSR distance and time spent in a higher HR zone (i.e., >90%HRpeak) tended to progressively reduce as the season progressed. This suggests differentiation between the volume and intensity of training being performed, comprising both internal and external load measures, highlights that these different factors of load do not necessarily follow the same periodization [33, 145]. However, the continued reduction in load variables shown in the present study differ from those of elite Italian soccer players reporting no changes in training load variables (i.e., total distance, high-speed running and sRPE-TL) between the first and second half of the competitive season [102]. In general, these findings support that there is change of emphasis on the physical aspect of training between preseason and in-season, with load management being more prevalent.

The quantification of load performed between the three age groups (U16, U17 and U19) and across the three test periods can provide an important insight into the nature of the training loads they are exposed to. We observed notable age-group differences in different load variables [33]. For example, no difference was recorded for total distance or sRPE-TL between the three age groups over 4 weeks, while load variables representing higher neuromuscular loads (i.e., VHSR and ACC) were higher in the U17 compared to the U19 age group. These observations are different to previous reports from an elite youth soccer academy in the English Premier League that showed a progressive increase in high-speed running distance and sprinting loads from U12 to U18 teams [15]. Possible reasons for the differences between these studies are the different age groups investigated in the studies (i.e., U12-U18 vs. U16-U19), variations in training load variables reported, as well as the different academy regulations in England (i.e., the Premier League's Elite Player Performance Plan (EPPP)) compared to Italy.

With regards to the association between load variables and changes in aerobic fitness, it was surprising to observe that none of the load variables assessed in the present study was associated with changes in this fitness parameter. Indeed, systematic literature reviews (including the one conducted as part of this thesis) have found time spent above individualized high-intensity HR thresholds, positively influences players aerobic fitness levels, mainly during the preseason phase [60, 212]. Other training load variables such as distance travelled in individualized high-speed running zones (but not arbitrary threshold zones as used in the present study) have also been reported to have a large positive effect on changes in junior soccer players aerobic fitness [95]. However, the strength of relationships between the various training load variables and changes in aerobic fitness recorded in previous studies are inconsistent across the competitive season. For example, small relationships were reported between sRPE-TL and VHSR with changes in the same continuous running test in the first (d = 0.43 and 0.44 respectively) but not in the second half of the season (trivial to small effect sizes, *d* range = 0.06–0.41) [102]. The inconsistent relationships reported in the literature and the absence of relationships of 1- or 4-week load variables assessed in the present study show there is little evidence to suggest a clear dose-response relationship between the training load variables and aerobic fitness changes in elite youth soccer payers. An individual, complex relationship likely exists between the nature of the training stimulus and aerobic adaptations (i.e., cardiovascular changes, capillarisation, mitochondrial density etc) in young soccer players. The application of individualised thresholds for training intensities may be required to better investigate these relationships. However, future studies, investigating these relationships need to overcome the limitations of these previous underpowered studies by including large sample sizes and a mixed model analysis that can be used to account for contextual factors that may influence this relationship.

Whilst none of the investigated load variables were associated with aerobic fitness, the present results showed that the intermittent running capacity appears to be negatively influenced by high-intensity HR load (HR90%). This contrasts with previous findings in elite adult soccer players reporting high-intensity HR training, often referred to as aerobic training, to be essential for achieving improvements in players physical condition in preseason [81-83]. The small negative association with high-intensity HR training could be related to an “excessive” dose resulting in overreaching [92]. Although speculative, a recent study has reported a correlation between weekly time training at an intensity >90% maximum HR and the variables associated with overtraining, albeit in a non-athletic population [227]. However, both training duration and total distance have also been identified as having a large association with changes in HIT blood lactate accumulation in professional Italian soccer players [102], however, this was observed over much longer periods of the competitive season (10-13 weeks). Similarly, observations of a greater training duration in the week before a test were associated with greater improvements in intermittent shuttle running performance in 18 young elite players during in-season testing [90]. In the present study, a trend for exposure to VHSR was observed, but the general lack of relationships with external load measures in-season agrees with previous findings [102, 228, 229]. Overall, this suggests that both the acute and chronic training load have an association with changes in intermittent running capacity, with internal load measures having a stronger effect than the external load measures. This finding suggests practitioners should aim to manage the levels of internal load being prescribed and performed by youth soccer players, as it appears to act as a moderator of the desired physical outcomes [75].

The present results also showed a small positive effect of VHSR accumulated 4-weeks before a test and CMJ performance. These results highlight the importance of a neuromuscular stimulus provided by high-speed running in stimulating players neuromuscular capacity [230]. However, comparisons to previous studies are difficult due to different CMJ measures assessed (i.e., jump height as opposed to power output) over different training periods, ranging from 1 session to 32weeks [89, 91, 96]. Indeed, jump height exhibits limited changes in performance across these different timeframes [89, 91, 96]. However, like the observations for intermittent running performance, an increased session-RPE training load the week before the test session also had a small positive effect on CMJ performance. This suggests that assessing both constructs of load should be taken into consideration when planning and monitoring training. Indeed, increased VHSR distance can be positive for muscular outcomes. We acknowledge, however, that other measures of load may be more relevant to the acute changes and adaptations [212]. Unfortunately, we did not quantify the amount of time or load dedicated to resistance training. Therefore, we recommend that future studies should aim to better describe the nature of the training loads being performed (i.e., pitch-based, or gym-based, describing the type and intensity of drills).

Understanding the influence of training loads on physical adaptations induced in these specific age groups can provide practitioners with important insights for the training prescription process. The development of these diverse physical qualities in youth soccer, including aerobic performance [67], intermittent endurance running, and repeated-sprint ability [68-70] are essential to compete at a professional level. Collectively these findings indicate that youth soccer player physical fitness benefit from the increased levels of load performed during the preseason phase (following detraining offseason), particularly for intermittent running capacity. These loads are however not to be considered as beneficial for all aspects of soccer performance as they may concurrently dampen improvements in CMJ power measures. To adjust for these interference effects, future investigations are required to examine optimal periodization approaches. Indeed, the inclusion of more details regarding the technical-tactical training being performed and the physical intensity achieved across the different sessions can aid practitioners' comprehension of the load prescribed. This can grant a better insight into the stimulus influencing the dose-response relationship. Furthermore, the impact of maturation on the relationships between load and changes in physical capacities should also be considered [200]. Although not directly assessed in the presented study, the role of maturations status on physical development is well known, and these factors may confound any relationship with training load.

Despite the present study assessing the relationship between a wide array of training load variables in a relatively large sample of youth players, over an extended period, the relationships between these variables remain unclear. Indeed, establishing associations between accumulated load and physical fitness is a challenge. The present findings that only a limited number of relationships with a 4-week load and their different directions (i.e., only VHSR for CMJ and HR90% for HIT) were surprising. More details regarding the periodization of load within these time frames (from microcycle to mesocycle) are required. Verifying how the manipulation of training frequency, duration, mode, intensity, and distribution of training can each influence training outcomes remains an important problem for sports scientists to better understand [27]. Assessing the intensity and volume of load separately may help to shed further light on the nature of these relationships, differentiating between training and match load (i.e., start vs. non-starters), while taking individual differences into account. Future studies should aim to assess the efficacy of different microcycle structures on soccer players physical performance outcomes (management of fatigue, alongside timing and type of physical stimulus performed between matches). Such information can directly aid practitioners working in elite youth soccer to inform decision-related to training plans aimed at improving long-term adaptations in physical capacity.

CHAPTER NINE

Discussion and Conclusions

Thesis Findings

The goals of this thesis were to 1) describe the levels of training load being performed by elite youth soccer players, 2) reduce the number of variables that practitioners must manage and interpret as part of the load monitoring program, and 3) determine the associations between acute and chronic accumulated trainings loads and changes in players physical fitness levels. Each of these goals relate directly to the athlete monitoring process and were devised with the intention of improving evidence-based approaches in the prescription and monitoring of training with a specific cohort of elite youth soccer players. Targeting training prescription and training load control is considered critically important in elite youth soccer academies, where the emphasis is placed on players long-term athletic development. As such, an understanding of the differences in training between age groups and the factors that can influence training adaptations is required [212]. Identifying the training load variables to include in an efficient load monitoring system is fundamental to achieving this goal.

The collective findings of the studies in this thesis highlight that relatively little is known about the training loads performed by elite youth level soccer players and less is known about how these impact upon players levels of physical fitness. Furthering domain knowledge relating to these questions, is essential to achieve one of the main goals of elite youth academies; creating players that can cope with the training demands of professional football.

The findings from studies 1-3 can be directly applied to help practitioners to better understand the ‘way’ elite youth academies periodise training between different age groups. Describing the progression of weekly sRPE-training loads recorded between the U15 and U17 age groups and differences in the modulation of load across a weekly microcycle provides the first level of actionable insights that can inform the development of training plans for specific age-groups. We also observed a consistent pattern of weekly training loads with little variation between in-season training weeks. The present results showed the matchday to be the most intense session of the week for all age groups, and that there was a systematic reduction of both training duration and perceived intensity in the days leading up to a match. We also showed differences in the internal training loads between the age groups across a weekly microcycle and higher loads in “starters” compared to “non-starters”. These results suggest that periodisation strategies are used to prepare the team and individuals both for the matchday and to manage load and recovery in its aftermath.

The combined results of these studies identified a myriad of factors that can impact on player training load, including the age group, starting status, and time within a weekly training microcycle. These factors should be considered when developing training plans for elite youth soccer players. By gaining an understanding of the training and match loads experienced by each player, practitioners should be better informed on approaches that can be used to individualize future training in this specific population.

Despite internal load being identified as the stimulus for training induced adaptations [33], the training process is commonly described in terms of external load (n.b., likely because external load is easier to control than internal load measures). To manage the internal load, a greater understanding of the factors that can be adjusted to influence youth soccer players sRPE is required. Study 4 applied a linear mixed model to show that 3 variables (i.e., total distance, sprint distance and time spent in a moderate intensity heart rate zone) described 89% of the variance in sRPE and the model was not significantly different between any of the four age groups. These results highlight the importance of planning and controlling external load variables of total volume and very high-speed running when designing training sessions for specific sRPE goals and supports the inclusion of these factors in the training planning process. Collectively, these findings provide evidence for practitioners to utilize in their monitoring process, facilitating the training cycle (i.e., the planning, monitoring and feedback loop) and streamlining the procedures related to data collection and information being provided to coaches [231].

One of the key issues that practitioners face daily, is the management and interpretation of the vast amount of training load data collected and then interpreting these data in a manner that can provide actionable insights. Studies 5 and 6 were conducted to reduce the large number of training load monitoring metrics that are available to practitioners in an elite youth soccer academy. Study 5 was the first attempt at data reduction through the application of an unguided Principal Component Analysis (PCA). However, the results from this analysis did not sufficiently reduce the number of variables in a manner that was feasible for use in practice (i.e., retention of ~25 variables). Moreover, there were also numerous inconsistencies in which variables loaded and how they loaded across the different components between the different age groups. These inconsistencies made this approach unattractive for practical adoption as each age-group would require its own PCA for data reduction. These findings showed that a that a one-size fits all approach to data reduction of training load variables is not applicable.

The creation of a conceptual framework has recently been proposed as a useful tool for identifying the key components in an athlete monitoring system [62]. In study 6, a conceptual framework was developed to guide the selection of key training load variables that were then included in a PCA. This approach rationalised the inclusion of the different training load variables in the PCA. However, despite the attractiveness of agnostic statistical approaches to reducing data, the application of a PCA in this case was not practically useful as it did not contribute to further reducing the number of load variables adequately.

Importantly, the main themes that emerge from the two PCA's identify similar groupings of variables and constructs of load. These components relate to 1) the total volume of load, 2) acceleration load, 3) the quantity of high-speed running and 4) heart rate load. Interestingly the themes identified closely align with those selected in the conceptual framework based on a needs analysis, previous literature, and expert opinion. Therefore, this supports the inclusion of different constructs of load (i.e., external, and internal) and different aspects of load (i.e., volume and intensity) in a youth football player monitoring system.

Understanding the relationship between training load variables and physical fitness changes in elite youth soccer players can aid practitioners to optimise training prescription. The results of study 7 showed that a few select training load variables were associated with changes in youth players physical capacity. However, there were a limited number of relationships between load and fitness, and these were not consistent between time periods across the competitive season. These findings highlight the complexity of the dose-response relationship in sports such as soccer. It would be over simplistic to believe that these associations have a simple linear relationship that is valid for all players. The large number of possible confounders on this relationship and individual differences between players make it difficult to establish a clear understanding between training load variables and physical fitness changes.

Whilst expecting a clear dose-response relationship with fitness (and likely performance) is probably unreasonable, the findings revealed significant differences in the timing of improvements in physical fitness across the competitive season. In general, the preseason phase, in which higher volumes are performed, is crucial for obtaining improvements in players continuous and intermittent running capacity. However, in accordance with the fitness-fatigue model [119], the higher levels of load appear to dampen improvements in neuromuscular performance. This observation supports the inclusion of testing a range of relevant fitness capacities, including cardiovascular and muscular characteristics, in youth soccer players [63, 232].

Practical Applications

The key themes emerging from this thesis are all directed at improving professional practice in an applied environment, with specific focus on an elite youth soccer academy in a world class soccer club. Indeed, the findings included in this thesis have been directly implemented back into the academy from which the data were collected (see Appendix 2). The specific application of these findings has improved understanding of the factors that influence the internal training loads described in studies 2-3. Whilst player load monitoring and adjustment is often applied at the team level, there have been adjustments made in the programming of training loads for individuals to better manage training. For example, increased focus is provided to the training completed by the non-starters compared to starters. Additionally, education practices with coaches have been applied to highlight the importance of controlling training drill and session duration, to manage training loads.

The variation in training load was also an issue of potential concern as variability is thought to be important to allow for adaptation to training. The results of study 3 showed limited variation in training load, and this appeared to be determined by the structure of in-season training weeks. In response to this, but within the constraints of the competition schedule (i.e., it is beyond the control of the academy), the academy management team have been searching for opportunities to plan increased variation in training dose across in the training schedule of all age groups (e.g., three loading days, one recovery day or other periodization strategies).

The main practical applications of studies 5 and 6 was the rejection of using an agnostic statistical approach to reduce data. Rather, these studies confirmed that the most practical approach to selecting training load variables was according to an established conceptual framework and according to the other measurement properties of these training load variables (i.e., their validity and reliability) and the expert opinion of experience staff (i.e., sport scientists, strength and conditioning coaches and football coaches).

A session builder (i.e., a tool in the clubs' in-house software that predicts session training load based on the training plan) has been developed help to ensure that the loads being prescribed are in line with periodization strategy and allow for changes to be made in the planning phase to help ensure that load demands can be achieved. Specifically, the results of study 4 have been used to develop an algorithm to estimate the players sRPE training load from training plan, which can be used to inform the prescription of "target loads" for each soccer training session.

In addition to these examples, there is also the impact that implementing the evidence informed practice included in this project has had upon the general academy. Indeed, with the adoption of this project within the academy, research has become a more integrated part of standard operating procedures. Whilst this has not directly resulted from the studies in this thesis, the entire project has assisted in embedding a culture of research into practice, and it would be expected that this will result in ongoing innovations and further refining the development of evidence-informed practices around athletes monitoring, support and care.

Recommendations for Future Research

The lack of consistency in findings between the studies documented in the systematic review and final study, make it very difficult to recommend a limited selection of training load variables for practitioners to focus on. This thesis has demonstrated that identifying the 'signal from the noise' in load monitoring data and its relationship to training outcomes may be more complex than previously thought. The studies included in this thesis consistently identified (relatively) similar constructs of load and factors (i.e., high-speed running, accelerations and total volume) as key to the training prescription process within youth academies.

Future studies should include larger samples and a more diverse multi-centre / multi-team approach. This process related to variable selection should also include a range the different stakeholders involved in the training planning phase (i.e., coaches, strength and conditioning coaches, medical staff etc.), identifying the monitoring tools deemed most relevant to that specific context. In this process we encourage future studies to include both internal and external load measures together, as to date, most studies have assessed one or other separately. Indeed, general study limitations found in the current thesis often relate to the inclusion of only one specific construct of load or limited selection of load variables without a specific criterion for their inclusion. The small sample sizes utilized in current literature and limited variance recorded in loads also limits the degree of insights relating to the directionality of modifications in load can induce. A more detailed reporting of the pitch-based training performed, and the volume and intensity of load recorded can also be beneficial towards improving the quality of information available.

With regards to the assessment of the complex dose-response relationships the addition of individualised thresholds in select training load variables (i.e., individualised GPS or heart rate derived variables) could help to add further information that was not included in the present studies. However, this could be a fruitless task if similar methods to the current study are repeated in a field-based study and the impractical nature of having to repeatedly change these thresholds for each individual player. Field studies will continue to be limited by the "noise" of field-based studies and lack of ability to control contextual factors such as diet, schedule and psychological factors that influence any dose-response relationships between training load and fitness measures within an academy setting.

Another aspect related to the physical fitness outcomes relates to the efficacy of different microcycle periodization (i.e., type and timing of the physical stimulus, as well as the inclusion of rest days) across different timeframes. An aspect that has gained some attention in recent years but that requires a more detailed analysis in elite youth soccer is the differences between planned training intensity and the stimulus performed during the training. Combined these additions to current research can greatly aid the decision-making process related to the training plan and long-term physical adaptations recorded by the elite youth soccer players.

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APPENDIX

Appendix One: Human Research Ethics Committee Approval

Dear Applicant

Re: ETH19-4420 - "The influence of training load on fitness and performance outcomes in elite youth soccer players"

Thank you for your response to the Committee's comments for your project. The Committee agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH19-4420.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:
Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed. The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat (Research.Ethics@uts.edu.au).

- The Principal Investigator will notify the UTS HREC of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.
- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC annually and notify the HREC when the project is completed at all sites. The Principal Investigator will notify the UTS HREC of any plan to extend the duration of the project past the approval period listed above through the progress report.
- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).
- The Principal Investigator will notify the UTS HREC of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.
You should consider this your official letter of approval. If you require a hardcopy, please contact the Ethics Secretariat.

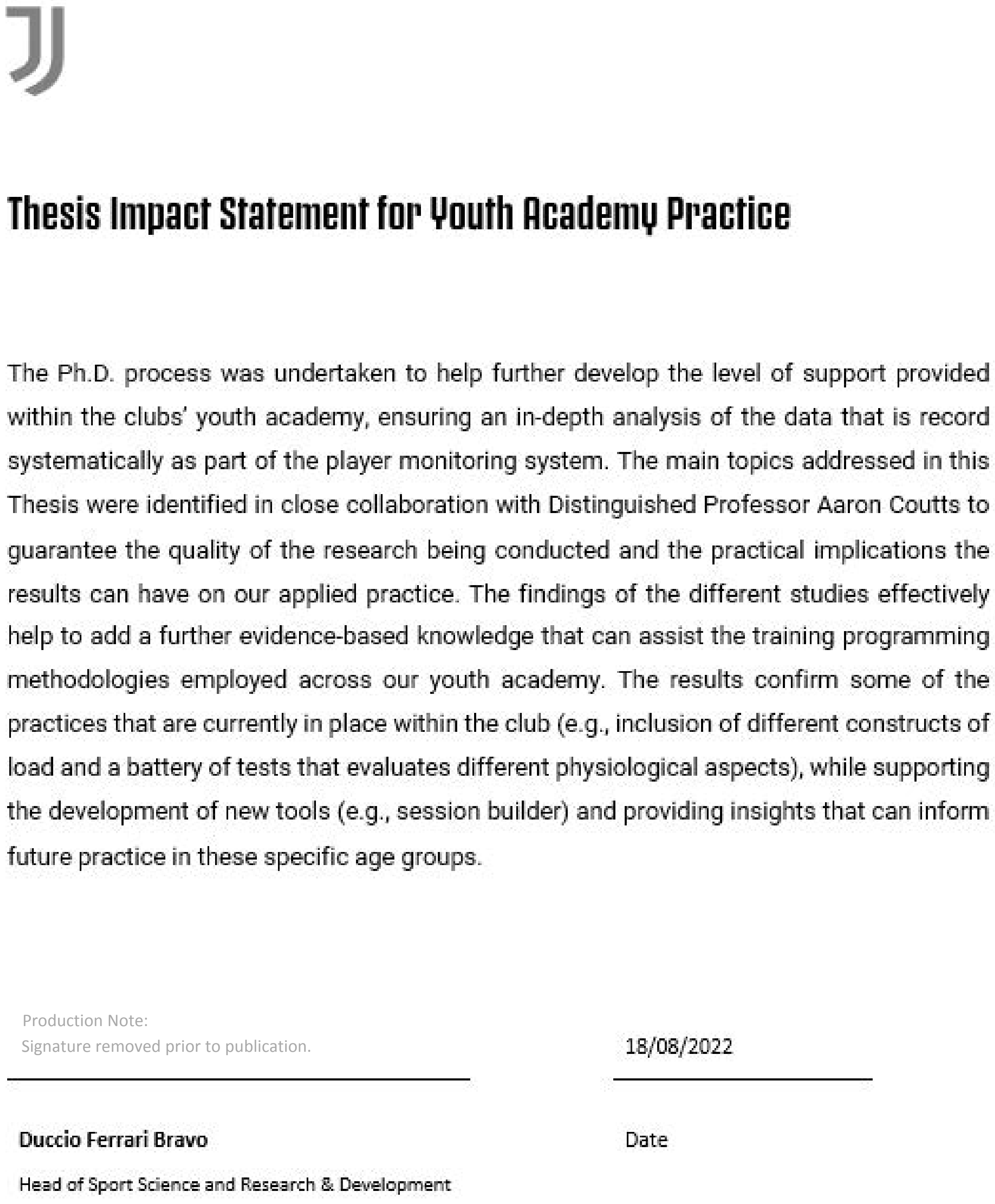
If you have any queries about your ethics approval, or require any amendments to your research in the future, please don't hesitate to contact the Ethics Secretariat and quote the ethics application number (e.g. ETH20-xxxx) in all correspondence.

Yours sincerely,

A/Prof Beata Bajorek
Chairperson
UTS Human Research Ethics Committee
C/- Research Office
University of Technology Sydney
E: Research.Ethics@uts.edu.au

Ref: E38

Appendix Two: Thesis Impact Statement



Thesis Impact Statement for Youth Academy Practice

The Ph.D. process was undertaken to help further develop the level of support provided within the clubs' youth academy, ensuring an in-depth analysis of the data that is record systematically as part of the player monitoring system. The main topics addressed in this Thesis were identified in close collaboration with Distinguished Professor Aaron Coutts to guarantee the quality of the research being conducted and the practical implications the results can have on our applied practice. The findings of the different studies effectively help to add a further evidence-based knowledge that can assist the training programming methodologies employed across our youth academy. The results confirm some of the practices that are currently in place within the club (e.g., inclusion of different constructs of load and a battery of tests that evaluates different physiological aspects), while supporting the development of new tools (e.g., session builder) and providing insights that can inform future practice in these specific age groups.

Production Note:
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18/08/2022

Duccio Ferrari Bravo
Head of Sport Science and Research & Development

Date

Appendix Three: Module 1 Certification of Completion

Graduate Research School

Research Integrity for Students

Certificate of Completion

This is to certify that

Darragh Connolly

[redacted]

has successfully completed

Module 1: Research Integrity and Code of Conduct

Production Note:
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Professor Lori Lockyer,
Dean, Graduate Research School

University of Technology Sydney

Date: 01/05/2019

Appendix Four: Module 1 Certification of Completion

Graduate Research School

Research Integrity for Students

Certificate of Completion

This is to certify that

Darragh Connolly

[redacted]

has successfully completed

Module 2: Plagiarism and Misconduct
Module 3: Risk Assessment
Module 4: Risk Management and Health & Safety
Module 5: Project Management

Production Note:
Signature removed prior to publication.

Professor Lori Lockyer,
Dean, Graduate Research School

University of Technology Sydney

Date: 01/05/2019