AN INVESTIGATION INTO THE CAPABILITIES AND AFFECTING FACTORS OF ISOMETRIC MID-THIGH PULL FORCE PRODUCTION IN ELITE YOUTH SOCCER PLAYERS

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“*The most effective way to do it, is to do it.”* Amelia Earhart

ABSTRACT

Elite youth soccer player's performance depends on a multitude of factors (Stølen et al. 2005). Muscular force production capability is of likely importance due to the frequency of powerful actions that occur within match play (Faude et al. 2012). Little is known though of the training undertaken at elite youth soccer academies to increase muscular force production capabilities particularly across maturation groups. There is also little evidence around the nature, or genetic influence on this variable in these populations. Greater knowledge on these areas would be beneficial to aid an understanding of performance and to plan practical interventions.

Eight weeks of training for players in the under 9 (U9) through to under 21 (U21) age groups (Chapter 3) were recorded to investigate the duration of each training type completed. The total training duration increased from U9 to U14 before reducing at U15 and then remaining unchanged through to, and including, the U21 age group. Soccer training accounted for 97 ± 4 % of session time in the U9 to U14 groups and 74 ± 3 % in the U15 to U21 groups. The remainder of training was made up of work that was not soccer based. The data in this case study suggest that training time is focussed on the technical/tactical development throughout the academy, particularly in the younger age groups.

Study 2, part A (Chapter 4) provided baseline isometric maximal voluntary force (MVF) data for players and an maturation-matched non-elite control group. MVF was slightly higher in the elite compared to control cohorts during

an isometric mid-thigh pull (IMTP, 118.29 ± 13.47 N compared to 109.69 ± 17.00 N). Such data may indicate that ability to produce force, specifically isometric MVF, may not be a crucial determinant of performance in elite youth soccer based on this sample.

The purpose of study 2, part B (Chapter 4) was to establish the effect of 8 weeks typical training on elite youth soccer players' IMTP MVF. This was also compared to a non-elite control cohort matched for maturation status and not undertaking training. Isometric MVF did not change in either group over the 8 week period (P = 0.386). These data suggest that this elite youth soccer training simply maintained current strength levels and was not sufficient to elicit increases in isometric MVF.

Study 3 (Chapter 5) examined variations in four separate genes, all identified as potentially having an influence on muscular force production capabilities: *PPARA* rs4253778*, NOS3* rs2070744*, COLIA1* rs2249492 and *VDR* rs2228570. Allele and genotype frequency was determined along with the influence of those single nucleotide polymorphisms (SNPs) on isometric MVF. Only *NOS3* was different in genotype distribution between cohorts with TT genotype showing 45.0 % and 30.4 % frequency in elite and control cohorts respectively (P < 0.001). Furthermore, no difference was seen between cohorts for isometric MVF data when comparing influence of any genotypes of any gene. These data provide novel information around genotype frequency in this population and would suggest that the gene variations examined here might not play a role in force production in these populations.

Overall, these findings suggest that muscular force production may be important for elite youth soccer performance, but that current training practices to improve this characteristic should be revised. This seems especially relevant given the lack of genetic association with force production in the gene variations examined here, i.e. elite youth soccer players do not appear to be selected based on a genetic predisposition for greater isometric force production capabilities.

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LIST OF ABBREVIATIONS

ACE I/D; Angiotensin-converting enzyme insertion/deletion

ACTN3; α-actinin-3

ANOVA; Analysis of variance

AU; Arbitrary unit

CI; Confidence intervals

CMJ; Countermovement jump

COLIA1; collagen, type I, α 1

CV; Coefficient of variation

DNA; Deoxyribonucleic acid

EMG; Electromyography

eNOS; Endothelial nitric oxide synthase

ES; Effect size

HWE; Hardy-Weinberg equilibrium

IGF-I; Insulin-like growth factor-I

IGF-II; Insulin-like growth factor-II

IMTP; Isometric mid-thigh pull

LB; Lower-body

LoA; Limits of agreement

LTAD; Long-term athlete development

MID; Mid-PHV group

mTORC1; mammalian target of rapamycin complex 1

MVF; Maximum voluntary force

NO; Nitric oxide

NOS3; Nitric oxide synthase 3

NR1C1; Nuclear receptor subfamily 1, group C, member 1

NRT; Non-resistance training based athletic development

PPARA; Peroxisome proliferator-activated receptor α

PHV; Peak height velocity

POST; Post-PHV group

PRE; Pre-PHV group

RCOD; Repeated change-of-direction

RF; Relative force

RFD; Rate of force development

RM; Repetition maximum

RPE; Rating of perceived exertion

RPM; Revolutions per minute

RSA: Repeated sprint ability

RT; Resistance training

RT-PCR; Real-time polymerase chain reaction

SD; Standard deviation

SNP; Single nucleotide polymorphism

SSC; Stretch shortening cycle

ST; Soccer training

TNST; Total non-soccer time

TST; Total soccer time

U9; Under 9 age group

U10; Under 10 age group

U11; Under 11 age group

U12; Under 12 age group

U13; Under 13 age group

U14; Under 14 age group

U15; Under 15 age group

U16; Under 16 age group

U18; Under 18 age group

U19; Under 19 age group

U21; Under 21 age group

UB; Upper-body

VDR; Vitamin D receptor

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CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Professional soccer clubs place great importance on training young players to perform in their elite first team squad. The developmental requirements of a young player in soccer are multi-factorial as their performance depends on components that include technical, tactical, psychological and physiological indices. Whilst there is a substantial research base on senior soccer players (Arnason et al. 2004; Hoff & Helgerud 2004; Stølen et al. 2005; Castagna et al. 2011), there is limited specific data available that clearly outlines the developmental processes relevant to the development of young soccer players. This is especially the case for information regarding the specific structure of the training programmes they complete.

An ergonomic perspective on elite soccer indicates that training for young players should involve a range of activities that are directly relevant to the performance requirements of the sport. These can be broadly divided into two categories; exercises performed on the field of play (soccer-specific exercises) and non-soccer specific activities carried out away from the pitch. Training on the field generally mimics soccer match play to some extent and frequently involves soccer drills, actual match play or variations of both (Wrigley et al. 2014). Off the field training is generally designed to improve a player's athleticism without the exact replication of soccer-specific movement patterns. This often takes the form of exercises to improve efficiency and quality of movement with, or without the application of an external load (Christou et al. 2006).

The specific detail of the accumulation of these training stimuli throughout the week, and season, are imperative to the effective periodisation of training and the long-term physical development of players (Matos & Winsley 2007). Specific details of the training structure and the training loads associated with on the field of play activity have been previously reported using observational techniques and objective measurement tools such as global positioning systems (Wrigley et al. 2012) in elite youth soccer players. This enables conclusions to be drawn regarding planning of on-field training.

Beyond on-field training, strength training is an important aspect of off-field training, as it is effective in influencing player performance (through increasing force production (Ferrete et al. 2014; Marques et al. 2013; Behringer et al. 2011; Thomas et al. 2009; Christou et al. 2006; Arnason et al. 2004; Hoff & Almåsbakk 1995) and/or decreasing injury risk in young and older players (Suchomel et al. 2016; Zouita, et al. 2016). This link to performance suggests it is practically important to attempt to also quantify strength training (as well as other off-field activities) in elite soccer players, especially those in younger age groups. Currently, the lack of data on the quantification of this aspect of training may make it difficult to determine the effectiveness of programmes and the impact that this type of exercise may have on player development.

As well as there being limited information specific to youth soccer training practices, there is also little information on the genetic makeup of young players and the role this may have in determining muscular force production capabilities. It seems reasonable to hypothesise that as a result of the undertaken systematic training; strength levels would be greater in elite than non-elite populations. Regarding differing genotypes of certain genes that may pertain to muscular force, it is difficult to make assumptions on distribution in this population, as soccer is not a sport hugely underpinned by muscular strength. Research is required to investigate the training practices, current strength levels to determine the importance of strength and if favourable genotypes are evident in these populations. A comprehensive investigation to provide such information could bring about changes to training structures and session focus and type, which could ultimately convert to improvements in on-field performance.

1.2 AIMS AND OBJECTIVES OF THE THESIS

The aim of this project is:

1. to investigate isometric force production capabilities in elite youth soccer players.

The PhD project will have the following objectives:

1. investigate the amount of training undertaken by elite youth soccer players with attention paid to the distribution of different training types

2. investigate the effectiveness of current training programmes completed by elite youth soccer players in increasing isometric maximum voluntary force production

3. investigate whether specific gene variations are associated with elite youth soccer player status and/or with maximum isometric voluntary force (MVF) production

The PhD project has the following hypotheses relating to the above objectives:

1. it was hypothesised that training would diversify and weekly training duration would increase in line with training age groups

2. it was hypothesised that the training currently undertaken would result in greater isometric force in the elite cohort when compared to a control group

3. it was hypothesised that potentially favourable genotypes of candidate genes studied here would be more prevalent in the elite cohort, which would also lead to an association between such genotypes and MVF

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The aim of this review is to critically examine relevant literature in an attempt to create a theoretical framework to support the aims and objectives of this thesis. The content is presented in four sections. Firstly, the demands of competition in elite youth soccer will be discussed. Secondly, an overview of the physiological determinants of muscular force production, with relevance to the maturing athlete, will be provided. A general overview of the impact of genetics in sport will then be presented in the third section. The final section will aim to evaluate existing recommendations with regards to strength training in young athletes.

2.2 DEMANDS OF ELITE YOUTH SOCCER

The demands of elite youth soccer are underpinned by a mixture of physiological attributes that span the aerobic/anaerobic continuum from an energy system perspective (Stølen et al. 2005) and stress a range of neuromuscular properties. When quantifying the total physical locomotor output, outfield players' total match distances range from 4356 ± 478 m in under 9 (U9) players (Goto et al. 2015a) to 8867 ± 859 m in U18 players (Buchheit et al. 2010). This exercise is primarily aerobic in nature as a consequence of the majority of actions, such as jogging or walking, being completed at sub-maximal intensities (Stølen et al. 2005). In addition to these low intensity activities are frequent intermittent powerful actions (e.g. sprints, headers, tackles) (Bloomfield et al. 2007; Bangsbo 1994), and such movements utilise the anaerobic energy system (Bangsbo 1994). The quantification of such movements by authors such as Buchheit *et al.* (2010)

have shown that sprint (> 19.1 km.h^{-1}) distances increases with age from around 186 ± 92 m to 410 ± 204 m and 666 ± 256 m in U13, U15 and U18 groups respectively. It should be considered that such differences may also not reflect developments in either the physical capabilities of players or changes in the nature of the game but simply differences in match duration and pitch size across age groups (Buchheit et al. 2010). Despite such differences, youth soccer match play is generally under-researched in comparison to senior soccer. This may be a consequence of the difficulty in applying contemporary analytical techniques (e.g. global positioning systems, Prozone ®) to such populations as youth soccer academies.

As key match activities are performed at high-intensities (Faude et al. 2012; Wong et al. 2010), it has been suggested that this component may be a key determinant of successful physical performances in the sport. However, relatively little data exists on elite youth players with respect to the energetic support for this activity within the research literature. Measuring relevant blood metabolites, such as blood lactate (BLa), could support the idea that these actions are anaerobic in nature. Currently, data related to BLa measurements suggest an increased contribution of high-intensity efforts to the total individual effort during match play (Bangsbo 1994; Molinos Domene 2013). To understand the importance of the ability to produce high-intensity efforts in youth soccer players through a greater understanding specific to such parameters would be advantageous.

2.2.1 THE POTENTIAL IMPORTANCE OF MUSCULAR STRENGTH IN ELITE YOUTH SOCCER

The high-intensity actions required during crucial match incidences are suggested to be largely influenced by muscular strength (Bangsbo 1994). In addition to these specific powerful actions (previously characterised by Faude *et al.* 2012), more general in-game actions have also been studied that may highlight the importance of force production capabilities in soccer. Generally, 1.9% of all movements have been described as “deceleration events” with 76.9% of decelerations performed after a sprint and 41.6% followed by “high-intensity” activities (Bloomfield et al. 2007). Repeated sprint ability (RSA) and repeated change-of-direction (RCOD) have also been investigated (Dellal & Wong 2013). As referred to earlier regarding total and sprint distance, Dellal & Wong found that when comparing players from U15 to U17 and U17 to U19 both RSA and RCOD also increased with progressive age groups (Dellal & Wong 2013). As muscular strength is associated with such actions and high-intensity soccer demands seem to increase with age, it is proposed that development of the attribute may be important throughout player development (Lloyd et al. 2013).

Although direct links between muscular strength and soccer performance are difficult, a significant relationship seems to exist between strength and activities that may be important to soccer performance. More fundamentally, for example, the link between acceleration and one repetition maximum (1RM) performance (Hoff & Almåsbakk 1995). It would seem reasonable to suggest that greater maximal voluntary forces (the highest force performed by the neuromuscular system during a single voluntary contraction ((Erskine et al. 2014)), MVF) would lead to greater relative force production (force scaled to body mass) and subsequent power production in actions that have relevance to the sport. This leads to the suggestion that greater force production could improve important soccer specific movements such as turning, sprinting and changing pace (Bangsbo 1994). Current suggestions are that attributes akin to those mentioned above, would be improved via the inclusion of specific strength training to improve performance (Dellal & Wong 2013). Specifically, it has been implied that younger athletes might not be able to compete with older counterparts should insufficient strength limit their performance in attributes such as speed and RCOD (Dellal & Wong 2013). They concluded the use of strength training should be part of a wider programme to improve crucial athletic parameters, and ultimately soccer performance. Though it is accepted it is likely that such training could yield ultimate increases in soccer performance currently there is little understanding of youth soccer strength training practices or levels.

2.3 THE PHYSIOLOGICAL DETERMINANTS OF MUSCULAR STRENGTH

Player strength is considered it to be a consequence of both specific training and/or genetic predisposition (Eynon et al. 2013). This section will focus on the potential of training to increase strength from a physiological standpoint. The role of genetics in underpinning strength and relative importance in youth soccer performance will be discussed later. Before considering fundamental training, principles associated with increasing muscular strength levels in youth soccer, an understanding of the underlying physiological mechanisms associated with strength and its development are important. During exercise, muscle tissue experiences a combination of four fundamental stressors: mechanical load, neuronal activation, hormonal adjustments and metabolic disturbances (Flück & Hoppeler 2003). These can subsequently lead to increases in muscular strength adaptive pathways that are linked to neural or morphological adaptations. Typically, it is considered that neural adaptations are responsible for increases in force production capabilities in pre-pubertal and novice athletes, whereas experienced athletes or those undergoing, or post-puberty also experience alterations to muscle architecture (Schoenfeld 2010; Marcotte et al. 2015). It would therefore be likely that throughout a soccer academy system (due to a range of chronological and training ages) both of these types of adaptation would be experienced. Currently though there is little specific scientific literature on the subject.

Increases in muscular strength as a result of neural adaptations occur via improved central drive (Jones et al. 1989), decrease in antagonist co-contraction (Milner-Brown et al. 1975; Carolan & Cafarelli 1992), as well as increased neural firing rate (Taylor & Gandevia 2008). It is likely that, as elite youth soccer academies possess age groups ranging from U9 to U21, increases in muscular force production will initially be a result of neural adaptation to training (Ozmun et al. 1994). Without adequate levels of circulating testosterone to stimulate muscle hypertrophy, children appear to experience more difficulty increasing their muscle mass consequent to a resistance training program compared with older populations (Ozmun et al.

1994). Previously Ozmun *et al.* investigated pre-pubescent youths (10.3 yrs.) undertaking 8 wk. resistance training (three sets (7-11 repetitions) of biceps curls with dumbbells three times per week). They saw 22.6 % isotonic and 27.8 % isokinetic force increases accompanied by 16.8 % increased integrated electromyography (EMG) amplitude though without changes in arm circumference or skinfolds (Ozmun et al. 1994). Such findings may not necessarily translate ultimately to improved soccer performance due to the specificity of training only the biceps though similar results may be expected to be seen in elite youth soccer. Currently though such mechanisms around strength adaptations are yet to be observed in this population.

As players start puberty and increase their physical training age, there is potential for any neural adaptation to be enhanced by architectural changes to the muscle (Keiner et al. 2014). Such architectural adaptations are in part controlled by the mammalian target of rapamycin complex 1 (mTORC1) pathway (Schoenfeld 2013). Typically, high-load strength-type exercise is required to cause muscle fibre growth by an increase in contractile proteins (Hoppeler 2016). This results in an increase in muscle cross-sectional area, and is often accompanied by a shift toward more favourable muscle fibre type properties (e.g. increased capacity for force production, Schoenfeld 2010; Erskine & Degens 2013; Marcotte et al. 2015). Though muscular hypertrophy is generally thought to be less common in pre-pubertal children (Keiner et al. 2014), it cannot be entirely overlooked (Faigenbaum et al. 2009). Faigenbaum *et al.* postulated it may be possible to increase muscle mass in prepubescent athletes, though they warned that this may require more intense, longer training programmes than are ethically appropriate (Faigenbaum et al. 2009). Such as approach should be considered unnecessary with strength increases elicited via potentially safer neural adaptation in younger athletes being preferential. Ultimately adaptations to strength training may be beneficial to youth soccer performance via potentially improving player’s ability to perform important explosive actions.

It has been recommended in Position Statements, that long-term athlete development (LTAD) programming considerations should be made regarding athletes maturation status (Lloyd et al. 2016). This is due to current data indicating that risk of injury is greatest around periods of greatest growth (Haag et al. 2016; Caine et al. 2008; Myer et al. 2009; Hewett et al. 2015; van der Sluis et al. 2013). This is obviously undesirable when seeking to improve performance via LTAD. When practitioners are looking to understand biological development, the terms growth and maturation are often used together, and at times even synonymously, but each refer to a specific biological activity. Growth refers to the increase in the size of the body as a whole and of its parts, whereas maturation refers to the rate and timing of progress towards a mature biological state (Malina et al. 2004). During adolescence (14 to 18 yrs. in boys), the occurrence of peak height velocity (PHV) is used as a reference for comparison of changes in body dimensions, proportions, composition and physical performance (Malina et al. 2004). It is during this (~1 yr.) period that increases in the fat free mass to fat mass ratio are greatest (Malina et al. 2004).

Such accelerations in maturation, as seen during PHV, are largely initiated via the endocrine system, with hormones regulating development by interacting with genes, nutrients and other environmental factors (Malina et al. 2004). Of particular importance are insulin-like growth factors (IGF-I and IGF-II), hormones linked to increased skeletal muscle mass (Malina et al. 2004; McMahon et al. 2013). Growth hormone and testosterone secretion, which also have anabolic properties, increase during puberty in males (Costin et al. 1989). Regarding maturation, Round *et al.* found circulating IGF-1 increased around PHV and tended to precede increases in testosterone levels, which reaches adult levels around 3 years post-PHV (Round et al. 1999). It is in part through increased secretion of these hormones that rapid increases in muscular force production capabilities occur (Malina et al. 2004).

These changes during adolescence are associated with accelerated growth in stature and body mass (Malina et al. 2004). When considering this impact on force production specifically, it is accepted that clear differences exist in muscle structure, size, activation patterns and function between children (up to 13 yrs. in boys) and adolescents (Lloyd et al. 2016). This predisposes children to a reduced force production capability compared to adolescents and adults (>18 yrs., Lloyd et al. 2016). For example, Seger and Thorstensson found that quadriceps torque measured using isokinetic dynamometry was greater in a longitudinal study of boys at 16 compared to 11 yrs. olds (Seger & Thorstensson 2000). The strength-age relationship is apparent when considering biological age (time to PHV i.e. early vs. late maturers, Philippaerts et al. 2006) as well as chronological age. This manifests with boys advanced in biological maturity generally being better performers than their later maturing peers of similar chronological ages (Malina et al. 2004). It has also been postulated that as maturation-related physiological changes (e.g., hormonal rise, central nervous system myelinisation) may favour different types of adaptation, the assessment of strength, power and speed are essential throughout this period (Meylan et al. 2014). Currently though, despite possessing an understanding around the physiology of increased force production in developing athletes there is little evidence suggesting whether such advice is adhered to. It is proposed that an understanding of a club's current training practices may help to optimise youth soccer academies LTAD during, and throughout these periods.

2.4 IMPACT OF GENETICS ON FORCE PRODUCTION PERFORMANCE IN ELITE YOUTH SOCCER

Aside from the influence of training, it has long been assumed that elite athletes may possess a blueprint for superior athleticism as a result of their genetic make-up (Eynon et al. 2013). There is strong evidence that the ability of skeletal muscle to produce force is influenced by genetic make-up (Thomis et al. 1998), with sub-optimal genetic makeup potentially reducing an individual's chances of high performance (Eynon et al. 2013; Proia et al. 2014). It is through genetic variants, or polymorphisms, that these advantages are likely achieved (Eynon et al. 2013). Elite performances in any physical attribute are considered polygenic traits with minor contributions from many interconnecting genes combining to affect the phenotype (these are summarised annually in *Advances in Exercise, Fitness and Performance Genomics* (Loos et al. 2015)). To date, there is no information on the genetic predispositions of elite youth soccer players that may influence muscular strength.

2.5.1 GENETICS AND STRENGTH – A BRIEF OVERVIEW

As previously mentioned, a player's strength is impacted upon by their genetics as well as any environmental factor such as undertaken training (discussed later). When attempting to determine the magnitude of the role genetics plays in muscular strength, twin studies have looked to show the heritability of strength performance as a physical attribute. Muscle strength and mass have varying heritability from 31 % to 78 % with large variance between muscle groups, contraction velocities and muscle lengths (Peeters et al. 2009). Explosive strength has been shown to have greater heritability (74 %) during 5 s intervals of a Wingate anaerobic test in 32 Caucasian male twins (Calvo et al. 2002). This subsequently provides a rationale for continued investigation into which gene variants might offer contribution to elite athlete strength performance.

Genetic variation

Such differences are brought about by alterations in the DNA sequence of a gene, which can be altered in a number of ways to produce variation and potential trait (or phenotype) differences. *Missense* single nucleotide polymorphisms (SNPs) are a change in one DNA base pair resulting in the substitution of one amino acid for another in the protein made by a gene. In *Nonsense* SNPs, the altered DNA sequence produces a stop codon, which can prevent the production of the protein. *Insertion/deletion (indel) polymorphisms* change the number of DNA bases in a gene by adding or removing a piece of DNA. As a result, the protein made by the gene may not function differently. *A deletion* changes the number of DNA bases by removing a piece of DNA (U.S. National Library of Medicine 2016).

Within genomics, *genotype* refers to how two alleles (one of two or more alternate forms of a gene or marker at a particular locus on a chromosome) of a gene combine in an individual (Malats & Calafell 2003). Due to the diploidy of humans there are two alleles for any given polymorphism. These alleles can be the same (homozygous, e.g. *ACTN3* XX or RR) or different (heterozygous, e.g. RX), depending on the allele inherited from each parent (U.S. National Library of Medicine 2016). Through polymorphisms, phenotype is dependent on whether an individual is a homozygote or heterozygote for favourable or unfavourable alleles. Over 200 gene polymorphisms have been identified in the literature to influence exercise performance with over 20 of those influencing elite adult athletic status (Eynon et al. 2013). It is the challenge of future research to determine which of these polymorphisms and more specifically, preferable genotypes, play larger roles in the genetic makeup of elite sportsmen (Ahmetov et al. 2009).

Of the polymorphisms associated with strength and power performance, the *ACTN3* R577X SNP has received the most attention. The *ACTN3* R577X SNP is the one of the only gene polymorphisms that shows a genotype and performance association across multiple cohorts of elite power athletes

(Santiago et al. 2008; Ma et al. 2013; Clarkson et al. 2005; Orysiak et al. 2015; Eynon et al. 2013; Orysiak et al. 2014). This common SNP of *ACTN3* results in an arginine (R) or a stop codon (X) at amino acid 557 of exon 16 on chromosome 11 (North & Beggs 1996). The stop codon prevents the α-actinin-3 protein from being produced in type II muscle fibres (Ma et al. 2013; Gineviciene et al. 2014; Erskine et al. 2014; Ahmetov et al. 2013). Through its interaction with the calcineurin pathway, the absence of α-actinin-3 leads to greater type I fibre composition (Seto et al. 2013). Thus, individuals with two alleles of the non-protein coding gene, i.e. XX homozygotes, have a smaller, weaker and less powerful muscle phenotype (Erskine et al., 2014) but one with greater fatigue resistance (MacArthur et al. 2007). A study in *Actn3* knock-out mice (MacArthur et al. 2007) (i.e. the equivalent to *ACTN3* 577XX genotype in humans) found smaller muscle mass due to shorter diameter of fast muscle fibres; lower grip strength; and higher endurance capacity, with knockout mice running 33 % further than their wild-type counterparts. Though difficult to say with certainty that these results are relevant and reproducible in humans, such associations between fibre-type composition differences and *ACTN3* R557X genotype differences have previously been found (North & Beggs 1996; Mills et al. 2001). This suggests that it is fibre type differences between those with different genotypes that produce the phenotypic differences. Specifically this SNP has been found to be more prevalent in elite senior soccer players (Eynon et al. 2013; Santiago et al. 2008), though there is currently no research on youth soccer players.

Other polymorphisms, such as angiotensin-I converting enzyme insertion/deletion polymorphism (*ACE I/D*, registered single nucleotide polymorphism rs4646994)) (Erskine et al. 2014; Gineviciene et al. 2014; Ahmetov et al. 2013; Ma et al. 2013), angiotensinogen (*AGT* Met235Thr rs699 (Karjalainen et al. 1999), skeletal adenosine monophosphate deaminase (*AMPD1*) Gln(Q)12Ter(X) [also termed C34T, rs17602729] (Lucia et al. 2006), interleukin-6 (*IL-6* -174 G/C, rs1800795) (Yamin et al. 2008), and mitochondrial uncoupling protein 2 (*UCP2* Ala55Val, rs660339) (Martinez-Hervas et al. 2012) polymorphisms have also been linked with elite strength performance, but with less consistent findings. Generally, small sample sizes and heterogeneous cohorts (often including athletes from multiple sports) tend to reduce the statistical power of such studies. Greater sample sizes in homogenous cohorts would potentially provide a more impartial identification of potential genes that may influence muscular strength.

Aside from those listed above, polymorphisms with little or no research into their effects on muscular strength include variations of the nitric oxide synthase 3 (*NOS3*), peroxisome proliferator-activated receptor α (*PPARA),* vitamin D receptor (*VDR*) and collagen type I α 1 (*COLIA1*) genes. Due to an understanding of their function, it is proposed that SNPs of these genes may be associated with muscular strength for the reasons explained below.

2.5.2.1 *NOS3*

As well as directly regulating vasodilation and blood supply to tissues, including working muscles, there is growing evidence suggesting that nitric oxide (NO) may be involved in human skeletal muscle glucose uptake during exercise (Gómez-Gallego et al. 2009; Eynon et al. 2013). Nitric oxide may influence force production via hypertrophy as it is a primary signal for skeletal muscle satellite cell activation (Long et al. 2006). The *NOS3* -786 T/C polymorphism (rs2070744) encoding endothelial NO synthase (eNOS) (which produces NO) is a candidate gene for explaining human individual variability of exercise related phenotypes (Gómez-Gallego et al. 2009). The $T^{-786} \rightarrow C$ substitution results in significantly reduced gene promoter activity and reduced endothelial NO synthesis (Nakayama et al. 2000). This SNP has previously been associated with elite performance in power-oriented athletic events (throwing, jumping, sprinting), with the T-allele being more prevalent in these elite individuals (Gómez-Gallego et al. 2009). Again, though, such analysis in elite youth soccer players is currently unavailable.

2.5.2.2 *PPARA*

The *PPARA* gene encodes peroxisome proliferator-activator receptor-α (PPAR-α). It is a central regulator of the expression of other genes involved in multiple steps of the lipid metabolism such as fatty acid uptake, transport, and oxidation (Proia et al. 2014). Consequently, *PPARA* shows increased expression in tissues involved in fatty acid utilisation, such as liver and skeletal muscle (Proia et al. 2014). Previously, Proia *et al.* found some variation in genotype distribution of the rs4253778 *PPARA* polymorphism between professional soccer players and sedentary volunteers (Proia et al. 2014). Specifically, the G-allele and GG genotype was more frequent in soccer players compared with controls. Ahmetov *et al*. also, reported the G-allele frequency was significantly lower in Russian power-oriented athletes (50.6%) compared to endurance-orientated athletes (80.3%) (Ahmetov et al. 2006). They also proposed the C-allele could be an advantage in power-type activities (Ahmetov et al. 2006) and therefore may be associated with greater muscular strength. This notion may also be reinforced by research suggesting it has been shown to have influences on body composition (Gineviciene et al. 2014), though no data exists in elite youth soccer players.

2.5.2.3 *VDR*

Vitamin D is known for its regulatory role in calcium and phosphate homeostasis and can mediate its effect through the formation of a complex with the vitamin D receptor (VDR) (Windelinckx et al. 2007). VDR is expressed in muscle, with *VDR* gene polymorphisms potentially affecting strength (Geusens et al. 1997; Santoro et al. 2014; Windelinckx et al. 2007). This occurs via *VDR* regulating vitamin D uptake in tissues, affecting myoblast proliferation and migration (Buitrago et al. 2013; Windelinckx et al. 2007). It has previously been shown that isometric and concentric strength of the quadriceps can be influenced by *VDR* genotypes (Windelinckx et al. 2007) though no clear mechanism was proposed for these phenotypic differences. No previous data exist on *VDR* genotype differences in elite youth soccer, making associations with muscular strength in this population impossible.

2.5.2.4 *COL1A1*

Type I collagen is the major protein of bone, composed of two alpha1 (I) and one alpha2 (I) chains (van Pottelbergh et al. 2001). These are encoded respectively by the collagen type I alpha1 *(COLIA1)* and alpha2 *(COLIA2)* genes (van Pottelbergh et al. 2001). As a result, much of the research into these genes focuses on bone mineral density. Van Pottelbergh *et al.* examined the association of the *COLIA1* Sp1 polymorphism with BMD and muscular strength finding a genotype-specific difference for hand-grip and elbow flexor strength (van Pottelbergh et al. 2001). *COL1A1* is thought to play a role in force transmission within the musculotendinous unit by differing genotypes altering transcription activity of *COL1A1* (Ficek et al. 2013). Authors were unable to offer further insight though this may lead to further associations between variations of the gene and muscular strength (Ficek et al. 2013) .

The research presented here suggesting potential links between these genes and muscular force production capabilities, supports further investigation into such associations. Greater investigation into how distribution of these genotype frequencies are associated with strength is also warranted to allow greater understanding of these SNPs in this population, as current data are relatively sparse. This is may have particular relevance due to the importance of forceful actions in soccer, which has been previously stated. Despite the broader potential importance of strength in soccer though it should be made clear that genetic testing, in relation to a single attribute should not be considered as a gold standard talent identification tool. Despite the hugely competitive nature of high-performance sport it would be incorrect to identify genetic profiling as the newest frontier of athlete selection at this time. Despite the correlations between some genes and elite athletic performance highlighted above, there is currently no scientific evidence for the predictive value of genetic profiling in sports performance (Vlahovich et al. 2017). With specific reference to soccer this is likely due to the combination of physical attributes required to be successful (as well as the non-physical skills required) (Guilherme et al. 2014). Despite this, it should be considered that when conducted under the correct ethical rigour, that genetic profiling may in time be of use to athletes. Such information around genetic associations with muscular force production capabilities may allow for certain individuals to have training tailored to address areas of potential weakness. Similarly, should genotypes have associations with muscular properties, this may result in players training schedules being individualised to allow optimal recovery or adaptation periods that may otherwise be unknown to practitioners. Currently though, due to lack of evidence, even these practices are discouraged in genetics research Position Statements (Vlahovich et al. 2017).

As a result of the paucity of data around specific genes and elite sporting performance, initially it would be useful to have an understanding of how genotypes of certain candidate genes may be distributed within specific populations. Correspondingly, it may then be useful to have an understanding of how certain phenotypes relate to these genotypic distributions. Until such time, caution must be used to prevent athletes being provided with inappropriate advice about their suitability for training types or scheduling resulting from a lack of evidence-based interpretation of test results (Vlahovich et al. 2017). Beyond the potential benefits of increased understanding around the genetic underpinnings of strength, the phenotype is largely determined by training undertaken. The following section will provide specific information around training recommendations for youth soccer training.

2.5 TRAINING CONSIDERATIONS TO INCREASE ELITE YOUTH SOCCER PLAYER FORCE PRODUCTION CAPABILITIES

Having considered the available information around the influence of genetics on muscular strength, it is important to focus now on training. Improvements as a result of suitable training can be monitored via performance tests. This also allows evaluation of strength over time to optimise training for increased muscular strength via manipulation of such key variables as training type, frequency and intensity.

2.5.1 DETERMINING SUCCESSES OF STRENGTH TRAINING PROGRAMMES IN THE MATURING ATHLETE

As many soccer fitness coaches place importance on strength, the assessment of this attribute in a club's fitness testing battery is increasingly common (Paul & Nassis 2015). Strength tests specifically allow the evaluation of current strength levels as well as effectiveness of LTAD programming. Before having confidence in any test, the validity, reliability, and sensitivity of test methods and procedures must be established (Abernethy et al. 1995). Validity (the degree to which a test measures what it purports to measure) takes different forms. This includes test validity in relation to a criterion (predictive or concurrent); a construct (convergent and divergent) or the characteristics of the test (content and logical) (Ary et al. 2006). For example, when assessing muscular strength, a field-based measure (e.g. 1RM leg extension test) may be compared against a criterion measure (e.g. maximum isokinetic leg extension strength measured with an isokinetic dynamometer) to assess validity. Field-based measures are often looked upon more favourably in the applied setting due to practical and cost issues. Practitioners should endeavour not to sacrifice validity for practicality when making test selections (Currell & Jeukendrup 2008).

Reliability can be defined as the consistency or reproducibility of results when carried out on multiple occasions (Abernethy et al. 1995). It can be a constituent of: instrumental reliability (the reliability of the measurement device), rater reliability (the reliability of the individual administering the measurement device), or response reliability (the reliability of the variable measured) (Castro-Piñero et al. 2010). Test reliability may be influenced by its duration, mode and type as well as athletic status, and age of the individual tested (Hopkins 2000; Currell & Jeukendrup 2008). Appropriate test reliability is very important in an applied setting as intra- and inter-individual reliability are desired though often the opportunity to conduct long familiarisation periods may be difficult. As a result, tests allowing short familiarisation periods, though yielding good reliability and validity are highly desirable.

Finally, the usefulness of a test can be determined by its sensitivity, defined as the ability of an instrument to measure changes in a state (Hopkins et al. 1999). Essentially, any test must be adequately sensitive to detect systematic and meaningful changes at individual and group level (Hopkins 2000). This measurement characteristic can be evaluated by comparing test random changes (i.e., typical error of measurement representing test noise) with the smallest worthwhile change expected from (in this case) a training intervention (Hopkins et al. 2001). This again may be influenced by the ability of a practitioner to ensure their players are sufficiently familiarised with the test (within the realms of practicality) to reduce typical error.

Traditionally field-based tests of muscular strength employed at soccer clubs have included 1 RMs (Sander et al. 2013; Keiner et al. 2013; Naclerio et al. 2013; Peterson et al. 2004) and isokinetic (Requena et al. 2009; Seger & Thorstensson 2000; Bogdanis et al. 2015) and hand-held dynamometry (Sayer et al. 2002; Leyk et al. 2007; Grundberg et al. 2004), though the suitability and usefulness of these tests are not high, especially for younger individuals (Paul & Nassis 2015). Isokinetic tests can require high levels of familiarisation, which is not always practical in such applied settings. Repetition maximum tests and dynamometers also present limitations by offering little specificity to many team sports. In such settings, a multi-joint isometric test may be more appropriate, especially across chronological, training and biological ages. Such tests are easily administered, require minimal skill, are not confounded by velocity, and are easily standardised (Wilson & Murphy 1996). The reliability of commonly used strength tests is reported in section 2.5.1.1 below with specific reference to paediatric populations.

Beyond those used traditionally, a newer test gaining increasing popularity, is the isometric mid-thigh pull (IMTP), which may be considered a suitable test for this population. It allows multi-joint isometric testing, providing evaluation of isometric MVF and isometric rate of force development (RFD, (Kawamori et al. 2006)). Isometric tests also provide good reliability and relationships with high force dynamic movements (Kawamori et al. 2006; Wilson & Murphy 1996), including dynamic strength tests and explosive weightlifting movements (Nuzzo et al. 2008, data highlighting the reliability of specific strength tests in paedatric populations are reported in section 2.5.1.1). The specific benefits of the test are that it is designed to mimic the body position of the beginning of the second pull of the Olympic lift, the clean (Haff et al. 1997). It is at this point where force and velocity production is greatest (Haff et al. 1997). IMTP MVF and RFD correlate well with 1 RM squat and 5 m and 40 m sprint performance in adults (Wang et al. 2016). When comparing MVF alone to CMJ peak power and relative IMTP MVF with relative CMJ height, correlations have also been shown ($r = 0.75$ and 0.59 respectively, Nuzzo et al. 2008).

The IMTP also correlates with shot put and discus performance (Stone et al. 2007), which may suggest a carryover into upper-body strength. This also may be considered advantageous in soccer performance, especially in positions where body contact is more common (e.g. strikers and defenders). There is currently no data on youth soccer players' IMTP MVF or RFD. Such information could be useful for practitioners in postulating training prescription effectiveness (Sheppard et al. 2011). Wang *et al.* also supports use of the

IMTP due to good correlations with various dynamic performance measures (i.e. strength (r = 0.866), speed (r = -0.539) and agility (r = -0.523)) potentially underpinning competition success (Wang et al. 2016). In addition to its potential appropriateness with elite youth soccer players McGuigan *et al.* found correlations between IMTP MVF and 1 RM squat (r = 0.97), bench press (r = 0.99) and vertical jump (r = 0.97) in recreationally trained individuals (22 ± 1 yrs., McGuigan et al. 2010). This suggests the test may be suitable for non-trained individuals, thus allowing comparison between elite and non-elite populations by practitioners or researchers.

Offering further justification, specific to test protocol, Haff *et al.* has also previously found self-selected knee- and hip-angles during the IMTP to be within a narrow range (140 ± 7°; 138 ± 13° (Haff et al. 2015)). This is advantageous for practitioners looking to test large groups in short spaces of time when desiring to maintain reproducibility of data. Moreover, Comfort *et al.* found that for knee-joint angles of 120°, 130°, 140°, and 150° and hip-joint angles of 125° and 145°, no differences in peak force were seen (Comfort et al. 2015). This suggests that inter-participant comparison between more diverse populations less technically skilled with these movement types (i.e. young, or non-athletes) would be possible. From the criteria outlined above, the IMTP, as described by Haff *et al.*, seems to be a valid, reliable (ICC = 0.99, CV = 2.2 %) measure of isometric MVF (Haff et al. 1997). It is for these reasons that the IMTP is potentially considered a suitable test for measuring strength within an elite youth soccer academy. This could allow potential determination of LTAD programme effectiveness within such a setting.

Despite the data presented above there is little reliability data on the IMTP in young athletes. A more detailed review of the reliability of tests of maximal force production in this population is presented subsequently.

2.5.1.1 RELIABILITY OF STRENGTH TESTING IN PAEDIATRIC POPULATIONS

As stated previously, measurements of the maturing athlete can be difficult due to the changes that occur during adolescence. As a result, strength tests in paediatric populations may present different levels of reliability than those seen in adult populations. This section will focus on reported reliability of commonly implemented strength tests in paediatric populations. Historically, paediatric strength testing has relied upon field-based tests of muscular endurance, such as straight-arm hanging or number of press ups achieved in 1 minute (Wilmore & Costill 2004). Though this may be of value, the specificity of such tests with relation to sports performance, could be questioned. When looking to assess maximal, rather than the endurance of muscular strength characteristics, isometric tasks such as hand grip dynamometry have also been commonly used (as referred to in previous sections). The technological advances in paediatric strength testing that have led to the inclusion of such methodologies as isokinetic dynamometry and force plate use, have also led to the potential for increased reliability of subsequent data. It has been proposed that strength testing in children, irrespective of muscle action, displays test-retest variation of around 5-10 % (De Ste Croix 2007). As a result the implementation of familiarisation periods is important in providing the opportunity for the specific movements, neuromuscular patterns and demands of the test to become familiar to the individual in a desire to reduce variability (De Ste Croix 2007). This is especially important in paediatric populations as without sufficient confidence in test reliability results can be affected by natural strength gained during growth and maturation (Paul & Nassis 2015). As such, evaluations in the reliability of strength tests on this population should be stringent.

Repetition Maximum Testing

Historically, perhaps the most commonly implemented method of strength measurement in the field was repetition maximum testing. These tests allow a functional measure of neuromuscular force capability and are usually determined by lifting maximal loads (Meylan et al. 2015). Popularity of this method is likely due to it being relatively low-cost and requiring little specialist equipment. Such traditional methods of strength testing have previously been shown to have high reliability in youths. In 18 trained soccer players (12 – 15 yrs. old) 1 RM leg press was found to have high reliability ($r = 0.97$, CV = 2.8 %, Christou et al. 2006). In a mixed group of boys and girls (10.4 ± 1.2 yr. old) test-retest reliability of chest press and leg press 1 RM was also found to be good (ICC = 0.98 and 0.93, respectively (Faigenbaum et al. 1998)). Despite such favourable reliabilities found during RM testing, it is noted that again, familiarisation is important with these movements to prevent negating test reliability (Benton et al. 2013). This is likely especially important in highly technical weightlifting skills such as the power clean, which may also be used in RM testing. In youths, the power clean has been seen to be reliable though (ICC = 0.98) (Malliaras et al. 2009; Faigenbaum et al. 2012). Such a technical skill as the power clean though is unlikely to be suitable for the majority of non-weightlifting individuals. With reference to traditional 1 RM strength tests, it is considered practitioners should establish the cost-benefit ratio of these exercises, given the time demands of learning such potentially complex exercises (Tricoli et al. 2005). With this in mind, good reliability does suggest that, if administered correctly 1 RM testing can provide sufficiently sensitive data for practitioners on their young athletes.

Isokinetic Dynamometry

As previously stated, isokinetic dynamometry has become more popular in use and is considered by many the criterion measure of force, as it can provide quantification of a variety of muscle function indices (e.g., peak and average torque, joint angle of peak torque, work, and power) (De Ste Croix et al. 2003). Previously, good reliability has been reported of isokinetic actions of the knee (extension $r = 0.95$; flexion $r = 0.85$, (Deighan et al. 2003)) and elbow in 6 to 10 year olds (extension $r = 0.97$; flexion $r = 0.87$, (Blimkie 1989)). While in mixed group of boys and girls (8.8 ± 0.5 yrs. old) ICC of concentric knee extension was shown to be good (> 0.75) (Fagher et al. 2016). Previously in elite youth soccer players, isokinetic knee extension and flexion has also been shown to have ICC = 0.70 and 0.99 respectively (Rebelo et al. 2013). Despite these favourable reliability findings, several issues must be considered when using isokinetic dynamometry. For example, with further reference to knee torque, systematic bias has been shown in pre-pubertal soccer players in both concentric and eccentric actions (Iga et al. 2006). These improvements were shown to be 3 – 7 %, which were deemed to be relatively small. Also, despite the benefit of isokinetic dynamometry allowing assessments of dynamic actions, there is suggestion that higher speed assessments may be more likely to produce errors (Zakas 2006). It has also been noted that a methodology, shown to be reliable for a single joint, should not have assumed reliability on untested joints (Abernethy et al. 1995). This caution can likely be extended to prompt practitioners to consider whether specific populations have been addressed when researching reliability of specific tests.

Isometric testing using portable and hand-held dynamometry

Although laboratory-based isokinetic dynamometry has been highlighted as being the criterion measure for force measurement, field-based portable dynamometry is becoming increasing common in elite sport. With specific regard to isometric testing, there is favourable data regarding hand-grip dynamometry test-retest reliability (r = 0.92 (Blimkie 1989)). Other studies have found similar results in 6-18 yr. olds with ICC = 0.96 and 0.98 between test and retest when they adjusted the grip span of the dynamometer to the participants' hand size by means of age- and gender-specific equations (España-Romero et al. 2008; Ruiz et al. 2006). In boys and girls (7-12 yrs.) hand-grip dynamometry reliability coefficients for the right hand, left hand, and the sum of both hands have also been shown to be 0.90, 0.89, and 0.91, respectively in a study examining correlations between upper- and lower-body strength in children (Milliken et al. 2008). Perhaps more specific to sports performance, the isometric leg press in youth soccer players, has been previously shown to have good reliability (r = 0.95 (Gissis et al. 2006)). Using portable isometric dynamometry in young Australian Rules Football players, acceptable intra-rater test-retest reliability has been found for right hip abduction (ICC = 0.81) and left hip abduction (ICC = 0.84) (Malliaras et al. 2009). There has been some notion though that as the absolute force potential increases between muscle groups that this may negatively affect hand-held dynamometer reliability (Agre et al. 1987). Also, many portable dynamometers employ isometric tests, which it has been suggested may be less relevant to sporting performance, which are typically dynamic (McGuigan et al. 2010). taking these considerations into account the benefits of cost and ease of use of portable dynamometers is clear, though it seems there may be limitations to their use that require practitioner consideration.

In summary of these findings, it should be considered that RM testing has been found to demonstrate good reliability in young populations though technique proficiency is important (Faigenbaum et al. 2012). Isokinetic dynamometry has also been found to have high levels of reliability in this population though there are practical implications such as cost that may be a limitation of its use. Also, there is some suggestion that the lack of specificity to sporting actions may be a drawback of this testing type (Kellis et al. 1999). Consequently, a good compromise may be the use of portable dynamometry equipment, which has been shown in this section to provide reliable data in youths (Gissis et al. 2006). Despite this, ensuring familiarity of tests and awareness of maturation status is important to maintain the sensitivity of a measure without misinterpretation of error when working with young populations (De Ste Croix et al. 2003).

2.5.2 CURRENT RECOMMENDATIONS FOR OPTIMISATION OF YOUTH STRENGTH TRAINING

An examination of the available literature allows some critical evaluation of the available strength training practices for this population. Such an analysis may be useful for practitioners as there is currently no information specific to strength training practices of elite youth soccer academies.

Player age

While the importance of training for increased muscular strength is acknowledged, it is understood that appropriate programming is essential to yield optimal results. This includes considerations around and manipulation of training type, frequency and intensity. Prior to such considerations though, LTAD plans must consider when implementation of such training is appropriate. Position Statements suggest that a foundation or a physical “vocabulary” should be acquired during early childhood (Lloyd et al. 2016). This platform of physical competence then seems to allow more advanced motor skill development to follow (Lloyd et al. 2016). The available literature does not currently indicate any specific chronological age for the initiation of organised strength training though. As a consequence, specific direction on training initiation is difficult to make. Despite this, recent guidelines recommended that children should possess sufficient emotional maturity to accept and follow directions and possesses competent levels of balance and postural control (approximately 6–7 years of age) to participate in strength training (Lloyd et al. 2013; Myer et al. 2013). It has also been noted that children involved in organised sport (as in elite youth soccer academies) should be ready to participate in developmentally appropriate strength training as part of an LTAD plan (Myer et al. 2013). Specific strength training is also recommended from early childhood due to its suggested beneficial effects on speed and power (Comfort et al. 2014), physical performance (Behringer et al. 2011; Harries et al. 2012; Lloyd et al. 2013) and reducing injury incidence (Myer et al. 2011; Myer et al. 2013; Valovich McLeod et al. 2011). With these recommendations in mind, it is proposed that practitioners should shy away from appropriate implementation of such training among pre-pubertal players.

Regarding the specifics of strength training in pre-pubertal soccer players, few studies have examined the effects of long-term training interventions on muscular strength. Ferrete et al. (2014) looked at combined soccer and on-field strength training on jump performance over a 26-week intervention period. Twelve pre-pubertal (8 to 9 yrs.) soccer players improved their jump scores after performing squat-based training before soccer training compared to a control group (Ferrete et al. 2014). The authors concluded that this data demonstrated that such integrated training might be a useful addition to current approaches to pre-pubertal training programmes. This study did not measure jump performance during the 26 week intervention, which does not allow greater understanding of whether a shorter period would have elicited the same results. Also, the fact that only young children were tested does not allow understanding of whether these findings would translate to older youths. Finally, despite these findings it is unknown though whether such recommendations are currently being followed in elite youth soccer.

During puberty development occurs non-linearly and practitioners should be flexible and responsive to inter-individual variations during training programming (Faigenbaum et al. 2009). This includes variations in the timing, tempo, and magnitude of physical maturation, differences in psychosocial maturation, and differences in rates and styles of learning (Lloyd et al. 2016). For example, ‘adolescent awkwardness’, may manifest during a growth spurt period where an individual may experience temporary disruption in motor control and whole-body co-ordination (Philippaerts et al. 2006). During such periods, training programme adjustments may be made to reduce loadings and simplify or retrain exercise movement patterns (Lloyd et al. 2014). As a result, it is recommended that knowledge of a player’s PHV status should be known in order to make such adaptations to training. Currently it is unknown whether such adjustments are made within elite youth soccer strength training programming and it is felt such information would be valuable. it should therefore be reiterated that that appropriately designed strength training programmes can, and likely should, be safely implemented as part of a player’s LTAD plan.

Training type

Prior to consideration of what specific type of strength training may be most suitable to athletes at various stages of maturation, it is understood that significant and worthwhile changes can be made via continual exposure to various training types (Keiner et al. 2013; Keiner et al. 2014; Sander et al. 2013). Beyond this consideration around what different training types may be most effective based on the available literature will be discussed. Traditional resistance training methods (using free weights) is a commonly adopted training type in elite youth soccer. Anecdotally, from the academy in question, this is more prevalent post-puberty where coaches may feel more confident to implement such work than with younger athletes. As previously mentioned, strong correlations between sprint performance and strength have been found (Sander et al. 2013; Young et al. 2001), which would likely be advantageous in youth soccer performance. The former group suggested programmes finding low or no adaptation might be a result of short interventions (< 1 yr.) being insufficient to yield performance gains. When examining 134 elite youth players (from U15, U17 and U19 groups) performing strength training, involving front and back squats, twice a week for two years Sander *et al.* found significant performance increases for both lifts and 30 m sprint times (Sander et al. 2013). These data suggest that, when implemented correctly, and for sufficient duration, traditional resistance training may help to improve youth soccer performance. It could be questioned though whether RM performance (as used here) is an optimal way to measure strength in youth soccer players and whether a shorter intervention period could yield results, which would be advantageous. Also, despite providing evidence that increasing strength may improve characteristics desirable in soccer, it remains unsure as to whether the academy in question utilises programming to elicit such improvements.

Beyond traditional *weightlifting*, plyometric training is a popular form of physical conditioning. This approach typically involves bodyweight jumping-type exercises utilising the stretch shortening cycle (SSC) (Bedoya et al.

2015). This body-mass-loaded exercise type may be seen as more appropriate by some coaches resulting in greater implementation of its use, especially in younger athletes. In such populations Marques *et al.* found during 6 wk. combined jump and sprint training twice a week in elite youth (13.4 ± 1.4 yr.) players that jump and sprint performance improved compared to those solely undertaking soccer training, though it is possible this may have been in part due to learning effect (Marques et al. 2013). Thomas *et al.* also found those in a drop jump group (instructed to minimise ground contact time) and those in a countermovement jump group (instructed to gain maximum height) experienced improvements in vertical jump height though no change in sprint performance in youth (17.3 ± 0.4 yrs.) semi-professional soccer players. They found no differences between treatment groups and concluded both methods were worthwhile for improving power in youth soccer players (Thomas et al. 2009). It may be proposed though that to truly investigate effects on power, a more suitable measure of power (such as use of a force plate) may allow more accurate interpretation of their results. From these data, the addition of plyometric training in youth soccer players seems to have the potential to increase jump and sprint performance, which may be favourable to soccer performance. These studies are unable to provide detail of overall current training undertaken by these players though, which may also impact on these data.

In addition to looking at whether traditional resistance training or plyometric training may be more preferable at different stages of maturation, Lloyd *et al.* found that when performed twice a week for 6-wks. all training groups (traditional, plyometric or both training types) improved sprint and jump performance irrespective of maturity status (Lloyd et al. 2015). Specifically, they found plyometric training was more effective in pre-PHV cohort, whereas combined plyometric and resistance training yielded better results post-PHV. This also provides useful evidence for the point made earlier that any kind of strength training is likely suitable to elicit increases in muscular strength. Such information may allow for maturation-specific training programmes to be implemented potentially yielding more favourable results. Söhnlein *et al.* also found similarly that sprint time (20 m) improved following a period (16-wks.) of plyometric training in early- to mid-pubertal elite soccer players (Söhnlein et al. 2014). They found two sessions per week also improved standing long jump performance. Interestingly they concluded plyometrics had a beneficial effect on explosive actions though programme duration influenced the particular action. Specifically, they saw improvements in 20 m time after 16-wks. though long jump improvements were seen at 4, 12 and 16-wks. This information suggests that sufficient programme duration should be allowed if an increase in these attributes is to be recorded. This, relatively, large amount of information on the use of plyometrics in youth soccer suggests practitioners may consider this exercise type in their programmes. It may be considered favourable due to not requiring an external load. Also, research has shown lower volumes of plyometrics can be implemented provided it is done on a hard surface (Ramírez-Campillo et al. 2013). This may be useful for applied practitioners in offering a method of reducing training time (by using firmer surfaces) to elicit similar adaptation. Despite encouragement from available literature that traditional resistance training is suitable for children, such a method as plyometrics may therefore be favourable at least as an introductory method.

Beyond resistance training and plyometrics, another, relatively well researched (Nesser et al. 2008; Sharma et al. 2012; Prieske et al. 2016), less traditional training is unstable surface training. Its popularity, as with plyometrics, likely stems from it requiring no external load. Practitioners may look to consider such training as the importance of trunk muscle strength and stability has previously been described for performance enhancements in sport-specific activities (Kibler et al. 2006). This assumption was reinforced by cross-sectional studies showing significant associations between variables of trunk muscle strength and short-distance sprint, agility, and jump performance (Nesser et al. 2008; Sharma et al. 2012; Prieske et al. 2015). Prieske *et al.* suggested training on unstable surfaces may be important as performance in soccer often occurs on relatively unstable surfaces (e.g., jumping and landing on uneven natural turf, kicking a ball while being impeded by an opponent) (Prieske et al. 2016). They investigated thirty-nine elite youth (17 ± 1 yrs.) players performing a progressive core strength-training program for 9 weeks (2–3 times/week) on stable or unstable surfaces. They found trunk muscle strength, sprinting, and kicking performance improved following either training type. This suggests unstable surface core work may be less beneficial than suggested though they state it demonstrates the potential to improve core strength in this population. As training variation has been considered important in youth athletes (Lloyd et al. 2016) unstable surface training may be considered within an LTAD plan. However, there is potential that greater soccer performance benefits may ultimately result from traditional resistance or plyometric training. Prior to making an attempt to prescribe optimal training types though it would be advantageous to know how much time is afforded to such training. Information on both of these variables would be advantageous though currently little exists.

Training frequency

It is advised that the frequency of training, as with volume and intensity, should be considered regarding the abilities of the athlete involved (Faigenbaum et al. 2009). Specific guidelines around this measure in youth athletes are sparse, making it difficult to follow an optimal framework. One study, considering the required frequency to maintain strength in adolescence found that following 20-wks. progressive resistance training, one session per week was inadequate in maintaining training-induced strength gains in preadolescent males (Blimkie 1989). Conflicting evidence though found that the same frequency was as sufficient as a twice-weekly maintenance program in retaining the strength gains made following 12-wks. resistance training in adolescent male athletes (DeRenne et al. 1996). Despite this evidence being inconclusive it is considered that one session per week of strength training included within a programme of regular soccer training may be sufficient to maintain strength gains. This may be dependent on the strength levels of individuals involved (not made clear in studies cited) though such information may be useful for practitioners during periods of intense training where greater resistance training frequency may be difficult. It is unclear currently whether such recommendations are being adhered to though and it is considered unlikely in pre-pubertal individuals.

Training intensity

Previously in this literature review it has been highlighted that should strength training be programmed appropriately, historic fears around youth athlete safety during intense strength training are unfounded. With this in mind, a moderate to high intensity (in relation to an individual's 1 RM) is recommended during strength training (Faigenbaum et al. 2009). This is deemed appropriate as the forces experienced during sport and recreational activities are likely to be greater in both exposure time and magnitude than during appropriately programmed strength training (Faigenbaum et al. 2009). In youth soccer, González-Badillo *et al.* investigated moderate load and few repetitions per set combined with jumps and sprints (González-Badillo et al. 2015). They found that undertaking 26 wks. training additionally to regular soccer training elicited improvements in vertical jump height and, to a lesser extent, sprint performance (González-Badillo et al. 2015). They postulated that the, typically lower than usual, 50-65 % 1RM used might be more practical to implement in the applied setting. These findings may be especially useful in their applied nature though it should be considered that following systematic, progressive training, greater intensities may be used, which could lead to greater adaptation. Again, it is felt that future studies may look to identify current training practices as it is felt this may allow programme criticism and adjustment ultimately leading to improvements in programming and increased strength.

Other Programming Considerations

Aside from considering programming to optimise performance, it should be contemplated how it is essential for minimising risks of too much specific training at a young age. Such “early specialisation” has been categorised as early-age involvement in one chosen sport during the period of early-to-middle childhood (< 13 years) with no subsequent participation in the other sports or activities available (Moesch et al. 2011). Such incidences can lead to increased frequency of high volume, intense competitive activities that are highly structured and focused on a single sport with potentially insufficient time for rest and recovery (Bergeron et al. 2015). Despite there being rationale that such an approach may lead to improved development and subsequent performance, associated risks can be detrimental. Specifically, specialising early within a given sport is suggested to increase the potential for increased injury risk; social isolation and burnout (Lloyd et al. 2014). Perhaps most crucially, the American Medical Society of Sports Medicine recently stated that early sport specialisation may not lead to long-term sporting success (DiFiori et al. 2014). This increased risk of drop out in compounded by a potential for an increased injury risk. In youth soccer Cam-type deformities combined with femoral acetabular impingements have been found to be more prevalent in those who played intensive soccer versus controls (Agricola et al. 2012). As a result, recommendations have been made that include limiting frequent specialised practice sessions (<4 per week). It has also been suggested variation and diversity in physical activity and sports is essential in the early years of a child’s development to avoid risks of morphological abnormalities. (Read et al. 2016). It should therefore be kept in mind when programming for player development in elite youth soccer that intense participation in a single sport prior to physical maturation may increase the risk of overuse injury among other undesirable outcomes (Read et al. 2016).

The above recommendations around optimisation of strength training in youth soccer offer concepts for consideration for practitioners looking to include such training in order to increase muscular strength in this population. It is felt that knowledge around current practices regarding programming, testing methods, strength levels and potential genetic predispositions for strength are limited.

2.6 SUMMARY

During competition, elite youth soccer players cover large distances; these distances include bouts of high-intensity efforts such as sprints, jumping and tackling (Stølen et al. 2005). As it is desired these elite youths will progress toward elite senior soccer it is likely they would require high levels of multiple physical attributes. This would include the ability to express muscular force production underpinning the actions linked to key match incidences (Faude et al. 2012). It is therefore fair to presume practitioners would desire optimisation of their athletes' LTAD models. To do this, awareness of current programming is essential. Research has increased in the area of soccer over the last few decades though research into youth players, and especially their strength training is sparse. Such knowledge, across all sub-senior age groups, would be useful to subsequently test its effectiveness. However, no studies have investigated academy-wide programming or the strength of players. As a result, it is difficult to make clear recommendations as to the most effective way to measure and develop muscular force production capabilities. Should such data be available it may then be possible to consider how to prescribe optimal training within the practical restrictions of youth soccer.

With the now relative ease with which individuals can be screened for different genotypes it would also be useful to investigate how youth soccer players compare to non-elite counterparts with respect to predisposition for genes that may pertain to muscular strength. Although some genes have strong links with the phenotype it would also be interesting to investigate further less well-researched genes that may have links to muscular strength. Overall, this understanding could be the first steps in developing greater understanding around the genetic make-up of elite youth soccer players.

CHAPTER 3

QUANTIFYING THE TOTAL TRAINING TIME AND ACTIVITY DISTRIBUTION OF ELITE UNDER 9 TO UNDER 21 YOUTH SOCCER PLAYERS IN THE ENGLISH PREMIER LEAGUE: A CASE STUDY

3.1 ABSTRACT

Aim The time completed by elite youth soccer players in different types of training in an English Premier League academy over an 8-week, in-season, period was investigated.

Methods The training of one-hundred-and-eighty-four elite soccer players, from the under 9 (U9) to under 21 (U21) age groups (age 9.4 to 18.4 yrs.; stature 1.38 to 1.82 m; body mass 32.2 to 76.2 kg) was recorded.

Results Total training time progressively increased between the U9 (268 ± 25 min/wk.) and U14 (477 ± 19 min/wk.) age groups with the majority of training time (96.5 ± 3.9%) consisting of soccer training and matches. Total training time was then subsequently reduced from the U14 to the U15 (266 ± 77 min/wk.) age groups, with no differences in training time between U15 and U21 (*P* ranged from 0.262 to 0.887). Only U15 to U21 players completed resistance training though no difference in session duration was seen between groups (*P* ranged from 0.247 to 0.626). The inclusion of resistance training coincided with an observed reduction in soccer training and match play when compared to the time spent in these activities for younger age groups (73.8 ± 3.2% of total training time).

Conclusion These data suggest the majority of training time is focused on technical development in elite youth soccer with a diversification of the completed activities and a reduction in total training time observed as chronological age increases.

3.2 INTRODUCTION

It has been suggested that it is important for professional soccer clubs to train young players to perform in their first team squads. The developmental requirements and considerations of a young player have also been discussed at length in Chapters 1 and 2. Although there is understanding around how training might be programmed to optimise development, data around current programming structure in elite youth soccer is sparse. It is considered that such data may be of use when looking to improve current long-term athlete development (LTAD) strategies.

It has also been previously highlighted that training for young players should include activities both relevant to the performance requirements of the sport and with a broader focus. It is also known that the specific detail around accumulation of such training is crucial to periodised progressive development (Matos & Winsley 2007). Previously specific details of the training structure and loads associated with on the field of play activity have been reported. Using a combination of subjective and objective data, player “training load” (rating of perceived exertion multiplied by session duration) increased through the U14 to U16 and U18 age groups (U14, 2524 ± 128 arbitrary units [AU]; U16, 2919 ± 136 AU; U18, 3948 ± 222; (Wrigley et al. 2012)) in elite youth soccer players. This is not unexpected, and is the result of a greater training frequency that accompanies the systematic development strategy used for the players in this sample (Wrigley et al. 2012). Such approaches to understanding the on-field training load have not been replicated in the training completed “off the field of play” in elite junior soccer. Chapter 2 outlined the potential importance of strength training in elite youth soccer in having the potential to increase muscular strength. This potential link to performance suggests quantification of strength training (as well as other off-field activities) may be important in elite soccer players, especially those in younger age groups. Lack of data on the quantification and distribution of different training types makes it difficult to determine the effectiveness of programmes on player development.

In response to such relative absences the aim of this study was to quantify total training time and the distribution of training activities completed by elite academy soccer players (ranging from U9 to U21 players) over an 8-week, in-season, period, including more specifically the strength training completed by players. It was hypothesised that training duration would increase as the age-group of the sample increased and that this increase in training duration would be accompanied by a diversification of training types. This information will help to facilitate a detailed understanding of training practices and their potential effectiveness in developing specific physical attributes in young players that may be important for soccer.

3.3 METHODS

Experimental approach to the problem

This observational cohort case study examined the distribution of training time across all players (U9 to U21) in the academy of an English Premier League soccer club. The purpose of this investigation was to compare the structure of each age group's training activities (e.g. soccer training (ST), non-resistance training based athletic development (NRT), match play, resistance training (RT) and rest). A specific focus on the RT component of this programme provided a more detailed analysis of this aspect of training; more specifically this included the determination of the total set count and the amount of upper and lower body training sessions completed by each age group.

Subjects

Players were recruited from the U9, U10, U11, U12, U13, U14, U15, U16, U18 and U21 age groups. Players included were placed into age groups by the club based on birth date. Occasionally players were involved in training targeted at different age groups. This happened more frequently in age groups above U15 (on these occasions individuals were considered part of the age group in which they trained). Across the data collection period there were 568 players playing above/below their age group out of a total of 9880 sessions (sum of total sessions per age group multiplied by sample size of that age group). This was around 6% of the cases included in this sample. Inclusion criteria for the investigation demanded participants complete 85% of their specific age groups ST sessions.

One-hundred-and-eighty-four elite youth soccer players were monitored over an 8-week period during March and April of 2013-2014 (Table 3.1). The U18 and U21 groups were engaged in full-time training, five days per week along with one competitive match per week (90-min duration). The U15 and U16 age groups engaged in training on a part-time basis and participated in one match per week (80-min duration). The U9 to U14 age groups also engaged in training on a part-time basis and participated in one match per week (60-min duration). The study conformed to the Declaration of Helsinki and was approved by Liverpool John Moores University Ethics Committee. All participants provided written informed consent and for those under 18 yrs. of age, parental or guardian written informed consent was also obtained.

Table 3.1 Participants characteristic's (mean ± SD) for the Under 9 (U9) to the Under 21 (U21) age groups (*n* = 184) included in the sample for this investigation

Age Group	Age (years)	Stature (m)	Body Mass (kg)
U9 (*n* = 23)	9.4 ± 0.3	1.38 ± 0.07	32.2 ± 5.1
U10 (*n* = 21)	10.4 ± 0.3	1.43 ± 0.07	34.4 ± 4.5
U11 (*n* = 28)	11.4 ± 0.3	1.47 ± 0.07	37.1 ± 4.4
U12 (*n* = 24)	12.4 ± 0.3	1.53 ± 0.08	41.7 ± 5.5
U13 (*n* = 18)	13.3 ± 0.2	1.63 ± 0.10	47.7 ± 7.6
U14 (*n* = 16)	14.5 ± 0.2	1.68 ± 0.07	56.9 ± 8.9
U15 (*n* = 12)	15.3 ± 0.3	1.74 ± 0.05	61.2 ± 4.8
U16 (*n* = 12)	16.4 ± 0.1	1.81 ± 0.08	70.0 ± 6.0
U18 (*n* = 18)	17.4 ± 0.5	1.82 ± 0.06	76.2 ± 8.5
U21 (*n* = 12)	18.4 ± 0.9	1.81 ± 0.07	72.4 ± 6.2

Procedures

Weekly Training Overview

To evaluate the structure of weekly training sessions, specific sub-components were categorised according to their focus. The categories used to define sessions were ST, match play, RT, NRT and rest. Soccer training was defined as a programmed session devised to enable players to cope with the demands of match play (Bangsbo 1994). These sessions focused on players' tactical understanding and/or technical ability as well as recovery training sessions completed following matches. Match play was organised soccer matches, against other clubs. Age group dictated the duration of these matches. Sessions using external load (barbells, dumbbells, resistance bands etc. but not opposition players) were defined as RT. Sessions designed to improve movement skills (mobility, stability and strength) without the use of external loads were defined as NRT. Days when players were not scheduled to report to the academy were defined as rest. Session durations were recorded using a mobile phone stopwatch or clock and were defined by the fitness coach present (U15 to U21) or the soccer coach (U9 to U14). When reported by soccer coaches, data was inputted individually for each player into a database, which allowed accurate collection accounting for variances within the session. A sample of these data were cross referenced by the investigator who found 100 % agreement on all occasions.

Determining Training Regimes

All training was monitored over an 8-week period for all players. Match and ST duration was recorded either by the investigator directly (U16 to U21 groups) or was communicated from the coach of the specific group to the investigator via email (U9 to U15 groups). All RT sessions were recorded on individual training programme cards issued to the players to record the details of each session. Exercise, set and repetition count was prescribed by United Kingdom Strength and Conditioning Association accredited strength and conditioning coaches at the club. To determine RT regimes completed, session duration, exercise type and set number were evaluated for each player during each session. Duration was defined as the total minutes each resistance training session lasted. Exercise type was defined as whether it primarily had an upper- or lower-body focus. Set number was defined as the number of groups of repetitions completed in succession before a designated rest period. For U12 to U14 age groups NRT sessions required the coach to demonstrate an exercise, which was then copied by the group. This resulted in all players in that group completing identical training sessions. These sessions were then quantified using the session plan for each training session.

Statistical analyses

All data were initially assessed for normality of distribution according to the Shapiro-Wilk's test. Statistical comparisons between age groups for ST, match time, NRT, RT and UB, LB and total set count were subsequently performed using a one-way between groups ANOVA or the Kruskal-Wallis test where normal distribution of data were or were not found, respectively. Where significant main effects were present, Bonferroni post-hoc analysis was conducted to locate specific differences. 95% confidence intervals (95% CI) for the differences were also calculated and presented. Additionally, effect sizes (ES) were also calculated as the difference between the means divided by the pooled standard deviation, with the following quantitative criteria for effect sizes used to explain the practical significance of the findings: trivial < 0.2, small 0.21-0.6, moderate 0.61-1.2, large 1.21-1.99, and very large ≥ 2.0 (Hopkins 2006). All analyses were completed using SPSS for Windows (version 21, SPSS Inc., Chicago, IL) where $P < 0.05$ is indicative of statistical significance.

3.4 RESULTS

Overview of Weekly Training Schedule

Soccer training was programmed on five occasions per week in the U18 and U21 age group, four times per week in the U11 to U16 age groups and three occasions per week in the U9 and U10 age groups (Table 3.2). Resistance training was undertaken by the U15 to U21 age groups. This was programmed once a week for U15s and twice a week for U16 to U21 age groups. Non-resistance training athletic development was undertaken by the U12 to U21 age groups. Typically, this occurred twice per week. All groups were scheduled to complete one match per week during the period studied.

Table 3.2 Overview of typical training activities for Under 9 (U9) to Under 21 (U21) players. Sessions included are soccer training (ST), non-resistance training athletic development (NRT), matches (M), resistance training (RT) and days on which no formal training is completed (Rest).

	U9	**U10**	**U11**	**U12**	**U13**	**U14**	**U15**	**U16**	**U18**	**U21**
Mon	Rest	ST	ST	Rest	Rest	Rest	Rest	Rest	ST	M
Tues	ST	Rest	Rest	ST, NRT	ST, NRT	ST, NRT	ST	ST	ST, NRT, RT	Rest
Weds	Rest	ST	ST	ST	ST	ST	ST	ST, NRT, RT	ST	ST, NRT, RT
Thurs	ST	Rest	Rest	ST, NRT	ST, NRT	ST, NRT	ST	ST	ST, NRT, RT	ST
Fri	ST	ST	ST	ST	ST	ST	ST, NRT, RT	ST, NRT, RT	ST	ST
Sat	Rest	ST	ST	Rest	Rest	Rest	Rest	M	M	ST, NRT, RT
Sun	M	M	M	M	M	M	M	Rest	Rest	ST

Total training time (total soccer training (TST) and total non-soccer training (TNST) combined) increased from U9 to U14 age groups (Figure 3.1). Specifically, an increase was seen between U9 and U10 (95% CI = -132 to -104, ES = -5.2, $P < 0.01$) though not between U10 and U11 ($P = 0.864$). An increase in total training time was also seen between U11 and U12 (95% CI = -98 to -67, ES = - 3.0, $P < 0.01$) but not between U12 and U13 nor between U13 and U14 ($P > 0.097$). From U14 to U15, a reduction in total training time was observed (95% CI = 162 to 261, ES = 3.8, $P < 0.01$). No further differences were seen from U15 through to U21 groups (P ranged from 0.262 to 0.887).

Total soccer time followed a similar trend to total training time in that it increased between U9 to U14 (Figure 3.1). Specifically, differences were seen between U9 and U10 (95% CI = -132 to -104, ES = -5.2, $P < 0.01$), although not between U10 and U11 ($P = 0.864$). A significant increase in TST was also seen between U11 and U12 groups (95% CI = -65 to -36, ES – 2.0, $P < 0.01$) though differences between the U12 to U14 did not reach statistical significance ($P \geq 0.431$). From U14 to U15, a significant reduction in TST was seen (95% CI = 210 to 276, ES = 6.3, $P < 0.01$). Total soccer time was not significantly different between any age group from U15 to U21 ($P \geq 0.4$). Total non-soccer time was zero in the U9 to U11 age groups (due to non-participation). Duration of this training type did not differ between U12 and U13 ($P = 0.06$), although there was a significant increase in TNST from U13 to U14 groups (95% CI = -13 to -6, ES = -2.0, $P < 0.01$), and from U14 to U15

(95% CI = -50 to -13, ES = -1.5, $P < 0.01$). No differences were seen in TNST between U15 and U21 age groups (P ranged from 0.121 to 0.874).

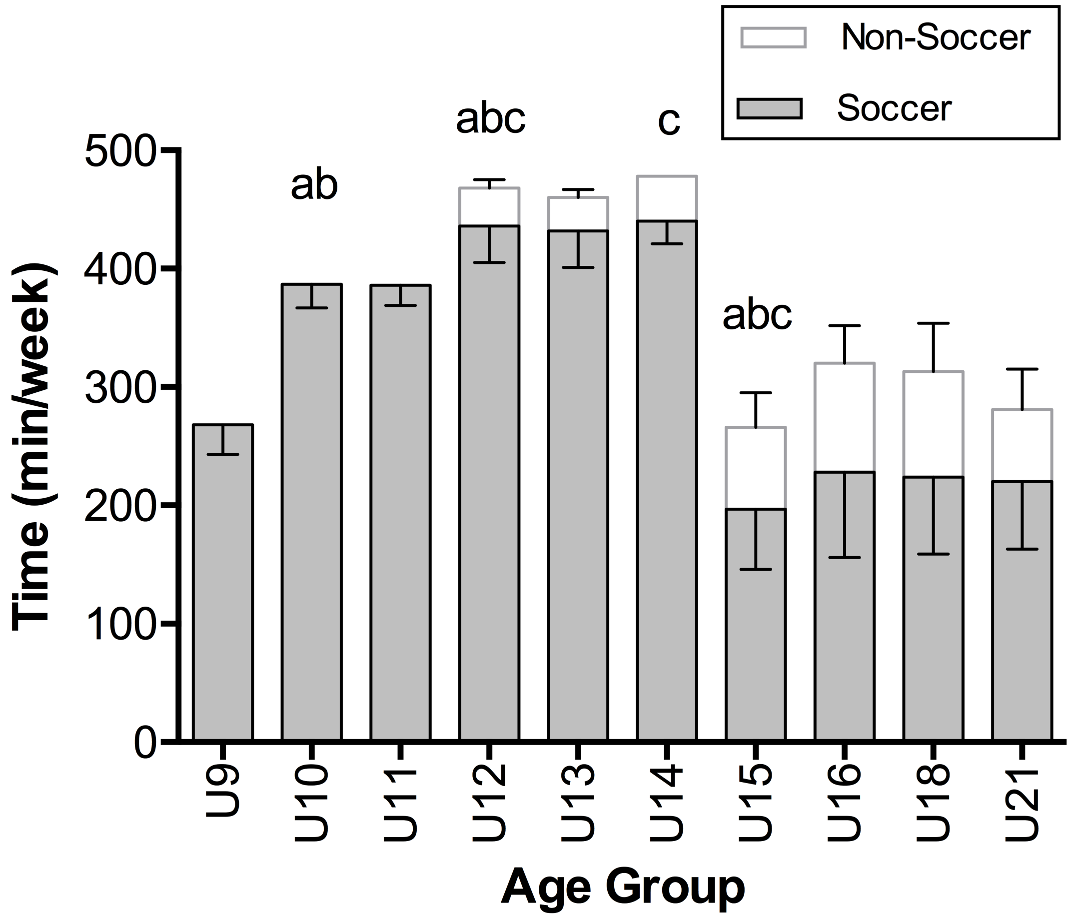


Figure 3.1 Breakdown of Under 9 (U9) to Under 21 (U21) distribution of total soccer (soccer training and match time combined; TST) and total non-soccer (non-resistance training athletic development and resistance training combined; TNST) time, over an 8 week (W1-8) period (min/week). a, b and c denotes significant difference between group and the previous age group for Total training time, TST, and TNST respectively $P < 0.05$.

No significant difference in match time was seen between age groups from U9 to U14 (all $P > 0.13$, Table 3.3). A decrease in match time was observed from

U14 to U15 groups (95% CI = 3 to 30, ES = 1.0, $P < 0.02$). Match time was then seen to increase from the U15 to U16 age group (95% CI = -48 to -14, ES = -1.6, $P < 0.01$) though no further differences were seen between any age group from U16 to U21 (P ranged from 0.682 to 0.833).

Table 3.3 Breakdown of Under 9 (U9) to Under 21 (U21) player match play time over an 8 week (W1-8) period (min/week). * denotes significant difference between group and the previous age group $P < 0.05$.

	W1	W2	W3	W4	W5	W6	W7	W8	Mean
U9	44	46	0	29	29	46	0	49	**30 ± 8**
U10	50	31	32	0	41	35	44	33	**33 ± 12**
U11	50	29	26	25	44	24	0	43	**30 ± 9**
U12	32	28	28	35	32	27	0	34	**27 ± 16**
U13	45	40	29	0	44	47	0	41	**31 ± 11**
U14	46	53	3	44	45	0	55	50	**37 ± 12**
U15	13	0	20	0	28	52	15	12	**20 ± 20***
U16	52	38	43	44	53	80	39	6	**51 ±20***
U18	54	57	43	52	47	74	47	47	**54 ± 26**
U21	50	49	58	65	66	58	6	58	**56 ± 23**

As the duration of match play for each age group was not identical it is important to look at the data with the influence of game time removed. Soccer training time (ST; not including matches) increased from the U9 to the

U10 age groups (95% CI = -128 to -104, ES = -5.7, $P < 0.01$, Table 3.4). There was no difference between U10 and U11 ($P = 0.623$) though an increase between U11 and U12 for ST was observed (95% CI = -63 to -44, ES = -3.1, $P < 0.01$). No difference was seen in ST between in any group from U12 to U14 ($P \geq 0.3$), although a large decrease in ST was seen from U14 to U15 (95% CI = 199 to 254, ES = 6.9, $P < 0.01$). When comparing the older age groups (U15 to U21) no difference was seen in ST (*P* ranged from 0.686 to 0.935) between any age group from U15 to U21, with these age groups performing less than half of the ST completed by the U12 to U14 groups (P < 0.001).

Table 3.4 Breakdown of Under 9 (U9) to Under 21 (U21) player distribution of soccer training time, over an 8 week (W1-8) period (min/week). * denotes significant difference between group and the previous age group *P* < 0.05.

	W1	W2	W3	W4	W5	W6	W7	W8	Mean
U9	215	227	258	243	219	247	223	270	**238 ± 23**
U10	351	360	343	360	339	356	360	360	**354 ± 17***
U11	355	358	355	358	348	358	358	358	**356 ± 15**
U12	415	400	415	394	409	408	418	418	**409 ± 19***
U13	403	390	413	372	393	417	408	417	**402 ± 27**
U14	416	420	403	407	383	398	405	390	**403 ± 19**
U15	243	156	246	104	92	74	167	235	**177 ± 42***
U16	115	168	169	191	186	60	124	199	**168 ± 63**
U18	148	126	117	172	233	137	192	197	**170 ± 52**
U21	119	85	109	51	158	229	216	185	**164 ± 51**

Non-resistance training athletic development was not undertaken by the U9 to U11 age groups (Table 3.2 and 3.5). From U12 to U13 NRT time was not different between groups (*P* = 0.06). From U13 to U14 there was a significant increase in the time spent on NRT (95% CI = -13 to -6, ES = -2.0, *P* < 0.01). NRT was then seen to significantly decrease from U14 to U15 age groups (95% CI = 6 to 21, ES = 1.5, *P* < 0.01). From U15 to U16, an increase in NRT was observed (95% CI = -30 to -3, ES = -1.0, *P* = 0.019), although no difference was seen in NRT between U16 and U18 (*P* = 0.311). When the U18 to U21 age groups were examined, a large decrease in NRT was observed; the time spent in NRT for these age groups was the lowest for any of the age groups (95% CI = 17 to 51, ES = 1.5, $P < 0.01$).

Table 3.5 Breakdown of Under 12 (U12) to Under 21 (U21) player distribution of non-resistance training athletic development time, over an 8 week (W1-8) period (min/week). * denotes significant difference between group and the previous age group $P < 0.05$.

	W1	W2	W3	W4	W5	W6	W7	W8	Mean
U12	58	58	58	0	0	0	29	58	**32 ± 7**
U13	28	57	57	0	0	0	28	57	**28 ± 7**
U14	60	60	60	0	0	0	60	60	**38 ± 0***
U15	27	20	21	14	27	0	39	31	**25 ± 12***
U16	30	29	30	65	69	7	39	40	**41 ± 19***
U18	78	46	22	42	62	32	53	52	**49 ± 23**
U21	12	12	19	5	12	7	31	15	**15 ± 21***

When looking at time spent in RT, no differences were observed between the age groups as players progressed from U15 (44 ± 18 min/week) to U21 (46 ± 18 min/week, P ranged from 0.247 to 0.626) age groups (Figure 3.2).

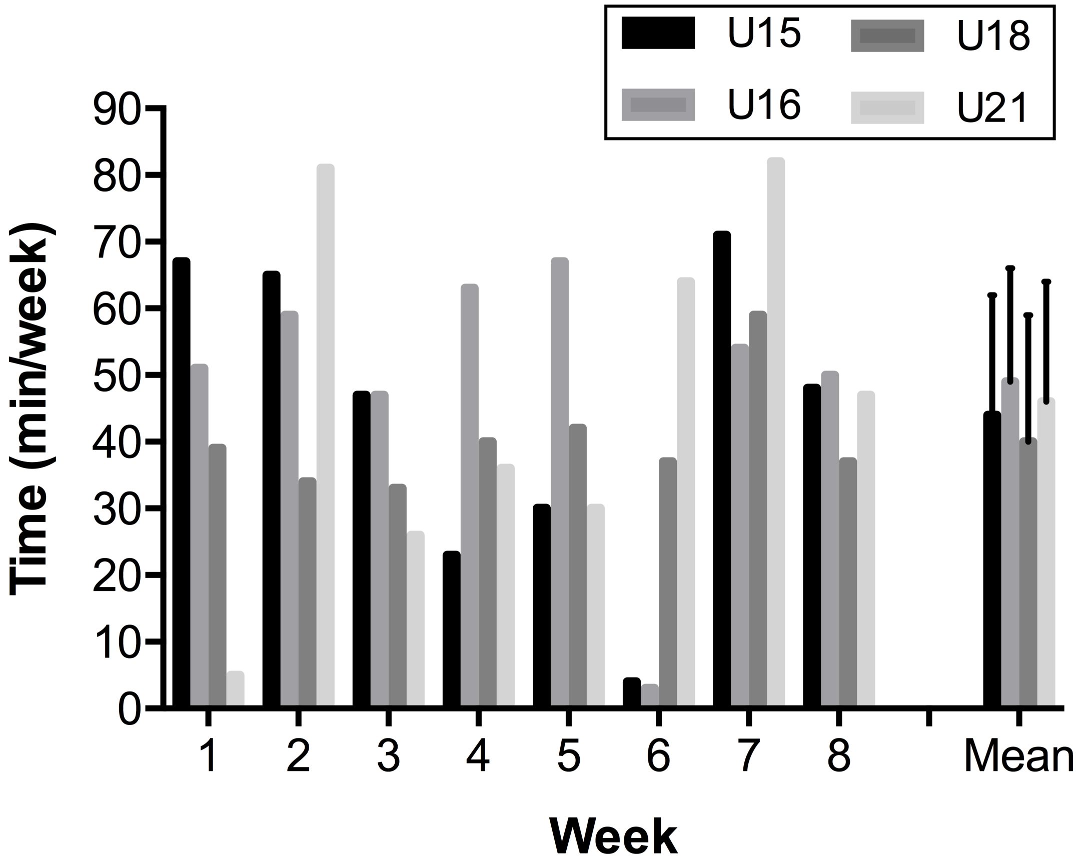


Figure 3.2 Breakdown of Under 15 (U15) to Under 21 (U21) player distribution of resistance training time, over an 8 week (W1-8) period (min/week).

Upper-Body, Lower- Body and Total Set Weekly Distribution

Total set count was not significantly different between U15 to U16 (19 ± 8 and 24 ± 8 set respectively, P = 0.207), although a decrease was seen between the U16 to U18 age groups to 16 ± 7 sets (95% CI = 1 to 13, ES = 0.9, P < 0.01). No significant difference was observed in total set count between U18 and U21 (21 ± 10 sets) groups (P = 0.155). Upper body set count (Table 3.6) did not differ between U15 and U16 age groups (*P* = 0.176), although it did increase from the U16 to U18 (95% CI = 1 to 9, ES = 1.0, *P* < 0.01), and from the U18 to U21 (95% CI = -11 to -1, ES = -1.0, *P* < 0.01) age groups. Lower body set count (Table 3.7) was not significantly different between any age group from U15 to U21 (*P* ranged from 0.096 to 0.456).

Table 3.6 Breakdown of number of upper body resistance training sets undertaken by Under 15 (U15) to Under 21 (U21) players over an 8 week (W1-8) period (sets/week). * denotes significant difference between group and the previous age group *P* < 0.05. Mean ± S.D. and range

	U15	**U16**	**U18**	**U21**
W1	18	21	7	0
W2	18	17	12	22
W3	14	16	10	13
W4	8	20	15	20
W5	9	21	10	14
W6	2	2	13	21
W7	19	16	16	30
W8	14	16	7	16
Avg/Wk	**13**	**16**	**11***	**17***
S.D.	**5**	**5**	**5**	**7**
Range	**3 - 21**	**8 - 20**	**0 - 15**	**0 - 32**

Table 3.7 Breakdown of number of lower body resistance training sets undertaken by Under 15 (U15) to Under 21 (U21) players over an 8 week (W1-8) period (sets/week) Mean ± S.D. **and range**

	U15	**U16**	**U18**	**U21**
W1	9	9	3	0
W2	8	10	3	10
W3	6	7	4	0
W4	2	10	6	1
W5	3	10	7	2
W6	2	11	5	5
W7	12	0	7	9
W8	9	7	7	7
Avg/Wk	**6**	**8**	**5**	**4**
S.D.	**3**	**3**	**3**	**4**
Range	**0 - 11**	**2 - 12**	**0 - 11**	**0 - 11**

3.5 DISCUSSION

The aim of the present case study was to quantify the total training time and the distribution of training activities completed by elite academy soccer players (ranging from U9 to U21 players) over an 8-week, in-season, period. This analysis was completed with specific reference to the off-field resistance training completed by players. Novel data were provided reporting that: 1) total training time was largely composed of on-field soccer-related activities in all age groups with TST increasing between U9 to U14; a general reduction in training exposure time is then observed for age groups above U15, which was not in line with the hypothesis 2) an increase in TNST at U15 coincides with a reduction in the proportion of TST (from 97 ± 4% in the U9 to U14 to 74 ± 3% of total training time for the U15 to U21 groups), which was in line with the hypothesis 3) RT was introduced at U15, although no difference in RT prescription (in terms of duration) is seen across subsequent age groups. This seemed to show that there was a greater focus on technical training than physical development. These data may provide a useful insight into the practical approaches associated with young player development at a professional club, and could be used to initiate comparisons with other talent development programs in elite sport with specific reference to training amount and type.

It is logical that advances in an individual's developmental stage may be accompanied by changes in their talent development program. This may be especially true for increases in the loads that are completed in training (Lloyd et al. 2013; Bergeron et al. 2015). Such trends have been previously recorded in the on-field training load completed by young soccer players (Wrigley et al. 2012). The progression of training exposure in these data (Figure 3.1) does not seem to follow the linear pattern demonstrated in previous work (Wrigley et al. 2012) who saw total weekly training load (training and match time multiplied by global session RPE) increase with age (U14, 2524 ± 128 arbitrary units [AU]; U16, 2919 ± 136 AU; U18, 3948 ± 222 AU; $P < 0.05$). This unexpected finding may be potentially explained by the specific talent development philosophy of the club in question. Older age groups at this club (U15 and above) seem to adopt a developmental strategy that focuses on the preparation (especially in a physical sense) around competitive matches rather than placing an emphasis on player development through the completion of repeated training sessions included in the programs. This emphasis on match play results in a structuring of the training exposure around competition that follows the principles of tapering (i.e. reductions in loading 1-2 days prior to the game). This inherently reduces the total accumulated training exposure across the week when compared to strategies, which do not use planning approaches that are game centred. It is recognised that using training duration as an indicator of volume is a limitation of this study. This restrictive approach to the evaluation of training load may not fully represent the “true” extent of the training stimulus if other parameters were also included to demonstrate the load completed by players. As such this data may not reflect the “actual” exercise that the players complete. The reduction in total training time seen beyond the U15 group though could be problematic as it coincides with periods of higher injury risk (Hewett et al. 2015). In turn, this could lead to a reduction in player robustness, which could affect LTAD. Though the focus seen during this period is not on match results *per se* there seems to be an emphasis on maximising the meaningful opportunities for development that competitive matches provide. A difficulty with this approach to weekly scheduling may arise for those who are not exposed to sufficient stimuli from match play, as is more common as age-groups progress. This approach, for those playing regularly though, seems to be in accordance with many long-term athlete development models that propose a shift from training to train toward training to compete (Lloyd et al. 2013; Lloyd et al. 2015). This may suggest that this approach attempts to prioritise the quality of players' development by using a model that focuses on competition rather than simply prioritising the total amount of training exposure. It is unclear though how this kind of approach may contribute to a players' robustness to injury or readiness to compete and train and greater intensities.

Although several studies have reported parameters related to training load (Wrigley et al. 2012; Coutinho et al. 2015; Goto et al. 2015b) in elite soccer players from U11 to U18, the data shown here provide the first account of training duration and distribution across all age groups within the academy system of a professional club for both on and off field activities. Training sessions for the U9 to U11 consisted entirely of ST and match play. For the age range U9 to U14, approximately 97 ± 4% of training comprised these activities. Such a focus on the technical and tactical development (i.e. the acquisition of skill) is supported by previous research, which illustrates that positive effects on fitness and motor control were associated with high exposure to sport (Fransen et al. 2012). The greater time afforded to technical skill development through soccer specific activities observed here provides a clear foundation for the players to attain a suitable level of competency in the specific skills required in the game (Behringer et al. 2011). It has also been suggested that such low/moderate structured technical training is more suitable for younger athletes for optimising development (in this case soccer training and matches) (Lloyd, RS et al. 2015). Others, however (Hind & Burrows 2007; Malina et al. 2004), have suggested that this period of childhood may be better suited to optimising physiological adaptations to non-soccer training. For example, a combination of NRT and RT may be more beneficial for the fundamental gross motor coordination (e.g. rapid changes in direction while maintaining body control) required by sports such as soccer (Lloyd et al. 2013; Bergeron et al. 2015). The inclusion of this type of training at an early age may also reduce an individual's risk of overtraining and the risk of stress-induced withdrawal (Hall et al. 2015). While insufficient evidence is available to suggest which of these two approaches is most appropriate for maximising athletic potential in young soccer players, the results from this study are supported by those of earlier works (Behringer et al. 2011; Fransen et al. 2012). These studies findings allowed inferences to be made that greater TST may lead to required development of fitness and gross motor control, which in turn, may lead to improved soccer performance. Future investigation may look to measure these attributes in an attempt to discover whether current training practices affect them as postulated.

An increase was observed in TNST from the U14 to U15 age group. This might suggest there is an elevated importance placed on athleticism in the development requirements of players as they progress through the age groups. In the younger age groups, training aimed at developing physical attributes such as strength is either not specifically included in the program or manifests itself as NRT (U12 to U14). Theoretical support for this approach may be provided by non-RT being shown to have potential to increase muscular strength (Dorgo et al. 2009). This in turn may be advantageous to soccer players (Stølen et al. 2005). The implementation of such training may not occur earlier, as it may impact on the development of skill and motor control through its influence on the time available for TST. Such scheduling of NRT prior to RT in a development program appears to be evidenced based; Lloyd et al. (Lloyd et al. 2013) indicated that, although RT may be suitable for young children, "competent levels of balance and postural control" (gained via the completion of training such as NRT) are essential for the optimisation of the training process associated with strength development. It would therefore seem that the developmental principles used here reflect the available theoretical frameworks associated with athletic development with respect to this aspect of the training program design.

To determine the focus of RT, the distribution of upper- and lower-body work undertaken by the players was examined. Lower body set count (Table 3.7) was observed to be lower than UB set count (Table 3.6). This may be unexpected in view of the specific demands of soccer, and the importance of lower body strength in youth sport generally (Lloyd et al. 2013). Irregular or insufficient training of the specific muscle group(s) involved in the sport may not create the desirable conditions for optimal adaptations to occur. When considering preservation of adaptation though, Lloyd et al. has suggested that the exposure required to maintain strength is small and may equate to only a single session per week (Lloyd et al. 2013). As this training frequency is observed in the U15 to U18 age groups, it may be assumed that this exposure could be sufficient for strength maintenance. Interestingly no difference in RT duration was seen between the different age groups included in this sample (Figure 3.2). This indicates that the level of RT did not increase with advancing age, although as previously stated a relatively simple indicator of volume (time) was used, which did not allow for conclusions to be drawn on associated load or intensity. This limits the ability to accurately quantify specific changes in the resistance training prescription that may occur across age groups. Such information may be an important supplement to future research studies conducted in this area. Also, and more broadly, the conclusions based on the data in this chapter are partly a function of the restrictive nature of the categories used to classify training. This case study offers insight to specific aspects of training, though understanding of a greater detail around the variables would allow further inferences to be made. This could be aided by dividing training types into further sub-categories. Although information on intensity is not presented here, it is likely that this progressive strategy (TST only from U9 to U12, TST and NRT from U12 to U14 and TST, NRT and RT from U15 to U21), which meets recommended guidelines (Lloyd et al. 2013), may improve muscular strength and athletic development, thus leading to improved performance and reduced risk of injury.

In summary, novel data report progressive and significant increases in the total training time completed by age groups from U9 to U14 age groups. Despite the limitations of the presented data in this case study, the progressive increase seen contrasts with a reduction in total training time from U14 to U15 age groups, as well as no differences in exposure between older age groups. These data suggest that the majority of training time in this group of young soccer players was focused on technical development. In contrast to the U9 to U14 groups, the U15 to U21 players also completed RT as part of their TNST. The inclusion of this type of training reduced the TST proportion of total training time completed. As players progress through the academy, this proportional shift, coupled with a general reduction in total training time, demonstrates that the focus on technical training may be reduced to favour a development strategy that is periodized around matches. Limited data, however, currently exist regarding optimising development in elite junior soccer players. Consequently, further research is needed to determine the most effective programming to support long-term player development.

CHAPTER 4

AN INVESTIGATION INTO ENGLISH PREMIER LEAGUE YOUTH SOCCER MAXIMUM VOLUNTARY FORCE, EFFECTS OF CURRENT TRAINING PRACTICES AND COMPARISON TO A CONTROL GROUP.

4.1 ABSTRACT

Aim The aim of the present study was to record normative isometric maximum voluntary force (MVF) data at baseline and after an 8 week period using the isometric mid-thigh pull (IMTP) from players throughout an English Premier League academy compared against a maturation-matched control group.

Methods One-hundred-and-fifty-five elite participants from an English Premier League academy's Under 9 to Under 21 age groups and ninety-three, maturation-, weight- and height-matched control participants performed the IMTP. Allometrically scaled (peak force divided by body mass$^{0.66}$) MVF was recorded. Performance tests were analysed in three maturity groups based on years from/to age of predicted peak height velocity (PHV): pre-PHV, mid-PHV, and post- PHV in elites and controls. One-hundred-and-forty-two and sixty-two of the elite and control cohorts respectively were retested 8 weeks later.

Results A small increase was seen in isometric MVF in the elites compared to control group at baseline (118.29 ± 13.47 compared to 109.69 ± 17.00 N, *P* < 0.001) though no difference was seen between groups after 8 wks. (*P* = 0.167).

Conclusion The small difference in baseline MVF suggests the training undertaken by this elite group is insufficient to elicit optimal muscular strength adaptation.

4.2 INTRODUCTION

The physiological demands of soccer have previously been outlined in Chapter 2 of this thesis. The myriad of movement competencies makes determination of the importance of a single attribute, such as maximal strength, to overall physical performance difficult (Andersson et al. 1988). The importance of testing the strength profile of those considered to be elite was also presented in Chapter 2. Knowledge of the strength of these individuals would also be beneficial in helping determine the effectiveness of training aimed at increasing strength within LTAD models. Such performance data may also provide future benchmarks for strength profiles needed to underpin soccer performance in these specific populations (Currell & Jeukendrup 2008). The inclusion of similar data from non-elite group would provide a useful comparison for such elite populations and help to further contextualise the importance and impact of strength and strength training in elite youth soccer.

When looking to conduct such strength profile assessments test choice is critically important (Young et al. 2014). Suitable tests should consider that the production of muscular force in soccer typically involves rapid whole-body, multi-planar actions. Further considerations around the suitability of strength test selection have been discussed previously in Chapter 2. One example of such a test is the isometric mid-thigh pull (IMTP). It enables practitioners to utilise force platforms when measuring both maximal force production and rate of force development capabilities. Such a test may be suitable in youth soccer players as it is representative of a commonly adopted position in multidirectional sport often known as the “ready” or “athletic” position (Suchomel et al. 2014; Garhammer 1993). Again, further evidence for the proposal of IMTP suitability and benefit are presented in Chapter 2. The evidence presented there promotes the potential use of the IMTP in establishing force production capabilities in youth soccer players both acutely (a one-off assessment of strength) and chronically (evaluating changes longitudinally as a consequence of training, maturation or both).

The present studies had two major aims: (1) To provide MVF data on soccer players attached to an elite soccer academy as well as a non-elite maturation-matched control group (2) To evaluate the effectiveness of a typical 8-wk. training period completed by the elite soccer players in increasing MVF. It was hypothesised that due to their elite status the soccer-playing cohort would display greater MVF than the control group at all maturity stages, and that these outputs would further improve as a consequence of the completion of an 8-wk training period.

4.3 METHODS

The experimental approach to this chapter was devised to make data collection as efficient as possible. In response to this the method of this work is split into two sections. The first section sought to consider baseline strength data. The second section looked to determine the affects of current training practices on MVF.

Part 1

Experimental Approach to the Problem

This cross-sectional study assessed the isometric MVF of elite youth soccer players. Participants were asked to refrain from physical activity for 24-hr before all testing sessions. Standing height (m), sitting height (m), and mass (kg) were measured. From this data participants' maturity status was determined using maturity offset (-29.769 + 0.0003007·Leg Length and Sitting Height interaction - 0.01177·Age and Leg Length interaction + 0.01639·Age and Sitting Height interaction + 0.445·Leg by Height ratio; Mirwald et al. 2002)). Maturity offset was then used to divide both cohorts into pre- (PRE), mid- (MID) and post-PHV (POST) groups for performance comparison. All testing was conducted on the same day for each participant with all data gathered over a two-week period (September/October 2015) for the elite group and a one-week period (May 2015) for the control group.

4.2.1 *Participants*

One-hundred-and-fifty-five elite players were recruited from the U9, U10, U11, U12, U13, U14, U15, U16, U18 and U21 age groups of an English Premier League soccer academy. Ninety-three local schoolboys, not linked to any elite sporting organisation were also recruited to form a control group. Participant characteristics are presented in Table 4.1. The study conformed to the Declaration of Helsinki, was approved by the Institutional Ethics Committee and consent was obtained from all participants/parents/guardians where appropriate.

Table 4.1 Participant's characteristic's (mean ± SD) for the pre-peak height velocity (PHV), mid-PHV and post PHV elite (*n* = 155) and control groups (*n* = 93)

Group	**Maturation Group (*n*)**	**Age (years)**	**Stature (m)**	**Body Mass (kg)**
Elite	Pre-PHV (88)	11.0 ± 1.5	1.45 ± 0.08	36.6 ± 5.8
	Mid-PHV (13)	14.1 ± 0.5	1.61 ± 0.07	48.6 ± 5.9
	Post-PHV (54)	16.8 ± 1.7	1.79 ± 0.06	69.0 ± 8.5
Control	Pre-PHV (44)	11.2 ± 1.3	1.45 ± 0.08	37.5 ± 5.8
	Mid-PHV (15)	13.7 ± 0.6	1.63 ± 0.05	51.2 ± 8.1
	Post-PHV (34)	16.2 ± 1.8	1.75 ± 0.05	67.1 ± 9.3

4.2.2 *Study design*

Warm up protocol for the isometric MVF assessment

Participants performed a standardised five min. warm up on a cycle ergometer (gear 6, ~80 RPM) (Keiser M3, Fresno, CA, USA), a dynamic whole-body stretching routine and three sub-maximal IMTP efforts using a back strength dynamometer (Takei A5402, Niigata, Japan). One sub-maximal IMTP was then completed on the specific testing equipment used for the IMTP pull prior to experimental trials.

Protocol for isometric MVF assessment

All testing was conducted on customised apparatus (see Figure 4.1) developed for the data collection. Rack pins and hooks of squat stands (Perform Better, Southam, U.K.) with ratchet straps were used to fix an Olympic weightlifting bar (Eleiko, Chicago, U.S.A.) to correspond to each participant's theoretical power clean second pull position, with knee and hip angles at 138 ± 3°; 134 ± 9°, respectively. This is similar to the testing position used in previous data (140 ± 7°; 138 ± 13°; Haff et al. 2015). Joint angles were measured with the use of a goniometer (Perform Better, Southam, U.K.) to ensure intra-position reproducibility between trials (Figure 4.1). The IMTP was performed with standardized procedures based upon the work of Haff et al. (Haff et al. 2015).

To collect isometric MVF data participants stood upon a force platform sampling at 1000 Hz (Pasco, Rosedale, CA, USA; data analysed using NMP ForceDecks (London, UK)). Following warm up, three maximal IMTP trials were performed with each trial separated by ≥ 30 s rest. Prior to the IMTP, participants were instructed to pull as hard as possible for ~ 2 s until being told to stop. Maximal efforts commenced following a verbal countdown of “3, 2, 1, pull” (Haff et al. 2015). Live force traces were used to help ensure a force plateau was subjectively observed. This gave confidence a maximum effort had been achieved. If the final effort resulted in the greatest force, another repetition was performed until this was not the case. All data analyses were performed on the effort that produced greatest MVF. MVF100 data was analysed using the same data analysis software with MVF being measured 100 ms after the initial onset of force production.

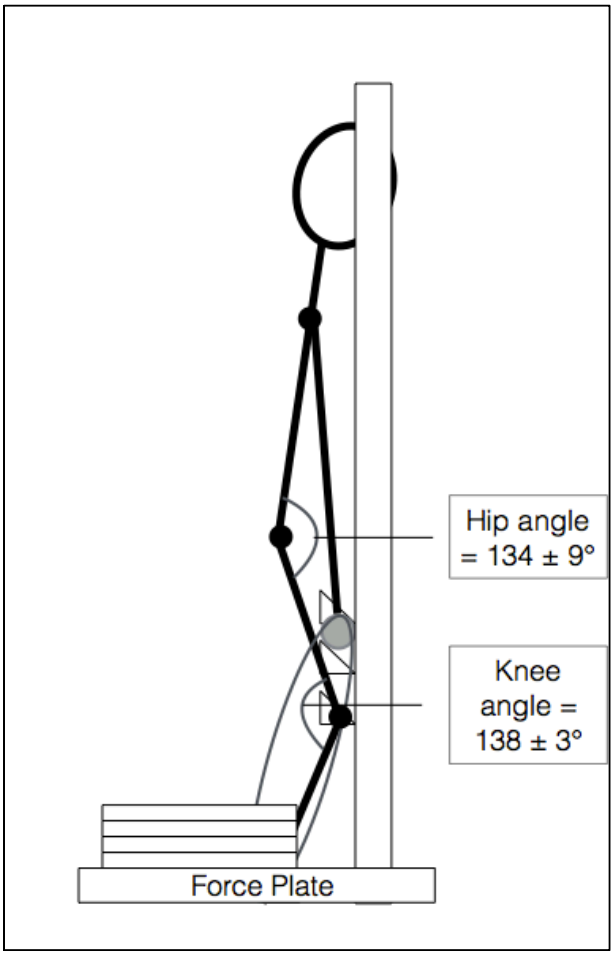


Figure 4.1 Isometric mid-thigh pull positioning schematic.

4.2.3 *Statistical analyses*

Allometrically scaled MVF was calculated by dividing peak force by body mass$^{0.66}$ (Folland et al. 2008). This was chosen as allometric scaling is recommended for comparison and normalisation of strength measures (Folland et al. 2008). All force data are presented as mean ± *SD (SD).* All data were initially assessed for normality of distribution according to the Shapiro–Wilk's test. Statistical comparisons between elite/control and maturation groups were subsequently performed according to a two-way between-groups analysis of variance (ANOVA) or the Kruskal–Wallis test. Where significant main effects were present, Bonferroni *post hoc* analyses were conducted to locate specific differences, and 95% confidence intervals (95% CI) for differences are presented. Effect sizes (ES) were calculated as the difference between the means divided by the pooled standard deviation, with the following quantitative criteria for ES used to explain the practical significance of the findings: trivial <0.2, small 0.21–0.6, moderate 0.61–1.2, large 1.21–1.99, and very large ≥ 2.0 (Hopkins 2006). All analyses were completed using SPSS for Windows (version 21, SPSS Inc., Chicago, IL) where $P < 0.05$ is indicative of statistical significance.

Part 2

Participants

One-hundred-and-forty-two of the initial elite participants were re-recruited from the U9, U10, U11, U12, U13, U14, U15, U16, U18 and U21 age groups of an English Premier League soccer academy. Sixty-two local schoolboys, not linked to any elite sporting organisation were recruited from the earlier part of the study to form the control group. Participant characteristics are presented in Table 4.2. The study conformed to the Declaration of Helsinki, was approved by the Institutional Ethics Committee and consent was obtained from all participants/parents/guardians where appropriate.

Table 4.2 Participant characteristic's (mean ± SD) for the pre-peak height velocity (PHV), mid-PHV and post PHV elite (*n* = 142) and control groups (*n* = 62)

Group	**Maturation Group (*n*)**	**Age (years)**	**Stature (m)**	**Body Mass (kg)**
Elite	Pre-PHV (83)	11.0 ± 1.5	1.45 ± 0.08	36.9 ± 5.9
	Mid-PHV (13)	14.2 ± 0.6	1.60 ± 0.06	46.9 ± 5.3
	Post-PHV (46)	16.8 ± 1.8	1.79 ± 0.09	69.0 ± 8.4
Control	Pre-PHV (27)	11.2 ± 1.3	1.45 ± 0.08	37.5 ± 6.1
	Mid-PHV (14)	13.7 ± 0.5	1.63 ± 0.05	51.2 ± 4.9
	Post-PHV (21)	16.2 ± 1.3	1.75 ± 0.05	67.1 ± 8.6

Experimental Approach to the Problem and Study Design

Part 2 of this study was conducted 8-wks. after a participant had completed Part 1 of the study. It was ensured by investigators that this section of testing was performed at the identical venue and time of testing. It was also requested participant activity in the 48 hrs. pre-testing was matched to that of Part 1. The pre-testing anthropometry, warm up and main testing protocol was also ensured to be as close to that used in Part 1 as possible to give confidence in the ability to compare resulting data. To ensure this investigation had a high percentage of participants retested during Part 2, minimum disruption other than strength testing was imposed on the control group. As a result, unfortunately, it was decided not to ask for activity data collection during the 8 wk. period from participants or their teachers or parents.

Statistical Analysis

Data are presented as mean ± SD. Data were checked for normal distribution with the Shapiro-Wilk's test. Data was allometrically scaled as in Part 1. Two-way repeated-measures analysis of variance (ANOVA) (Time x Group) was applied to test for main effects between week 0 and week 8 testing and between the 2 groups (elite vs. control) of all individuals who participated in both testing sessions. ES were calculated as in part 1. All analyses were completed using SPSS for Windows (version 21, SPSS Inc., Chicago, IL) where $P < 0.05$ is indicative of statistical significance.

4.4 RESULTS

Part 1 – Baseline isometric MVF assessment

Participant Characteristics

There were no differences between elite and control groups for age (P = 0.234), body mass (P = 0.643) or stature (P = 0.553). Characteristics for all maturation groups are shown in Table 4.1.

Allometrically Scaled IMTP MVF

Differences in MVF between groups are displayed in Figure 4.1 The elite youth soccer players (ESP) demonstrated a greater MVF when compared to the control group (CON) (95% CI = -13.55 to -3.65, ES = -0.241, P < 0.001, Figure 4.1) with ESP MVF being 115.42 ± 21.96 N compared with 109.36 ± 27.90 N. Maturation significantly influenced MVF with a moderate increase seen from PRE to MID (95% CI = -20.04 to -3.91, ES = -0.733, P < 0.001) and a large increase from MID to POST maturation (95% CI = -37.14 to -20.40, ES = -1.671, P < 0.001) of 98.06 ± 13.04, 107.91 ± 13.82 and 137.45 ± 20.84 N respectively. There was no interaction between group and maturation status on MVF (P = 0.167).

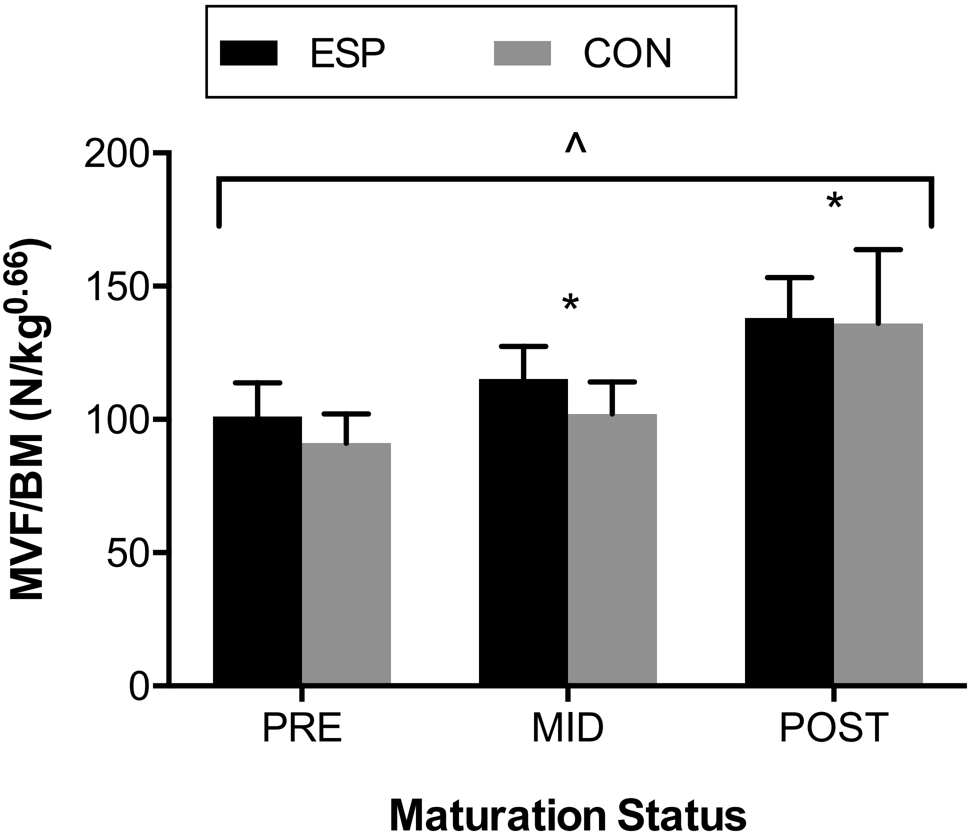


Figure 4.2 Isometric maximum voluntary force (MVF) normalised to body mass (BM) for elite youth soccer players (ESP) and control participants (CON) at pre-, mid- and post-peak height velocity. (* indicates a MVF increase between maturity group and the preceding group, ^ indicates a MVF increase between elite and control groups, $P < 0.001$)

Part 2 – Follow up testing 8 wks. post-baseline isometric MVF assessment

Participant Characteristics

There were no differences between elite and control groups for age (P = 0.133), weight (P = 0.560) or height (P = 0.775), with all maturation group characteristics shown in Table 4.2. The information in Table 4.3 illustrates a "standardised" 1-wk training schedule, determined from the average frequency of sessions in the 8-wk period of training at the time of testing, for the elite group. Further training data from a similar period is presented in Chapter 3.

Table 4.3 Frequency of training type (mean ± SD) for Under 9 (U9) to Under 21 (U21) age groups in the elite soccer players (sessions/week). N.B. Control participants were not undertaking any systematic training over and above that completed as part of school physical education lessons.

	U9	U10	U11	U12	U13	U14	U15	U16	U18	U21
Matches	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1
Soccer Training	3 ± 1	3 ± 1	3 ± 1	4 ± 1	4 ± 1	3 ± 1	4 ± 1	4 ± 1	3 ± 1	4 ± 1
Resistance Training	N/A	N/A	N/A	N/A	N/A	N/A	0 ± 1	1 ± 1	2 ± 1	1 ± 1
Non-Resistance Training	N/A	N/A	N/A	0 ± 1	2 ± 1	2 ± 1	2 ± 1	3 ± 1	3 ± 1	4 ± 1

Allometrically Scaled IMTP MVF

MVF following an 8-wk training period for the elite players are shown in Figure 4.2. Following the training (outlined in Table 4.3) MVF was not influenced by elite/control status or maturation status over time with no significant three-way interaction seen between group, maturation status and time, F (2, 198) = 0.957, P = 0.386. Additionally, when investigated further there were no influences on MVF from interactions between group and maturation status, group and time or maturation status and time, F (2, 198) = 0.092, P = 0.912, F (1, 198) = 0.126, P = 0.723 and F (2, 198) = 0.226, P = 0.798 respectively. This shows strength in ESP was not influenced by the training period.

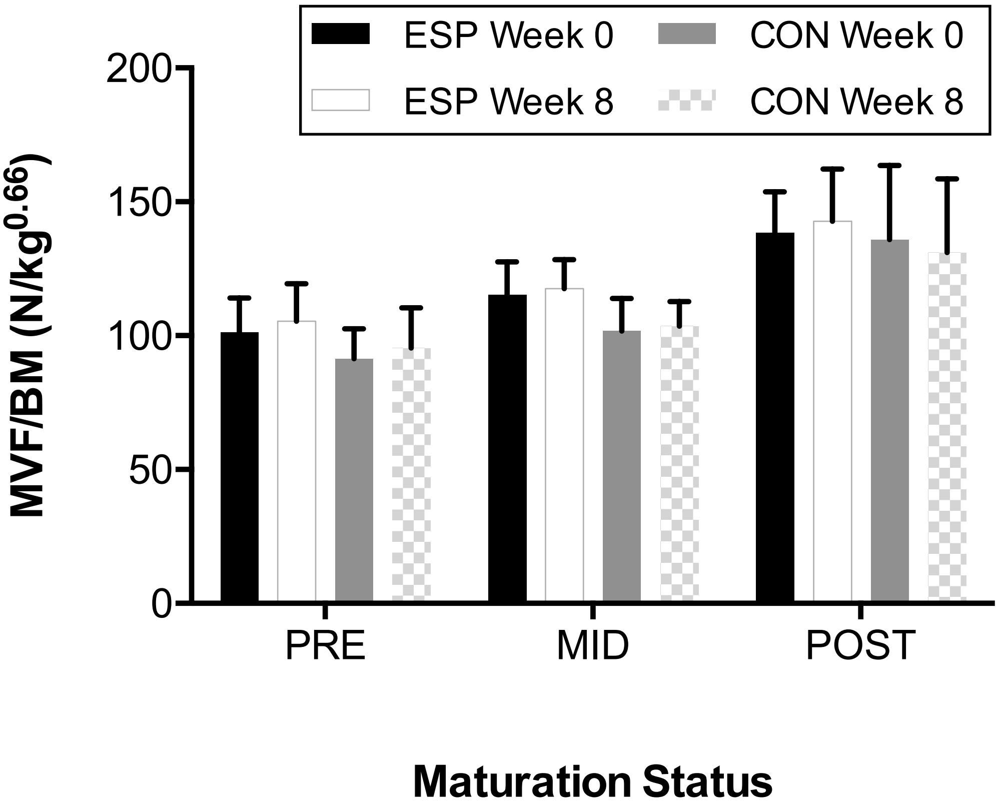


Figure 4.3 Isometric maximum voluntary force (MVF) normalised to body mass (BM) for elite youth soccer players (ESP) and control participants (CON) at pre-, mid- and post-peak height velocity at week 0 and week 8.

4.5 DISCUSSION

The first aim of this study was to provide normative isometric MVF data on elite youth soccer players throughout maturation compared with a non-elite cohort. The secondary aim was to re-measure the same variable after an 8-wk. training period also compared with a control group. Novel data reported a small increase in baseline MVF in elites (118.29 ± 13.47 N) compared to controls (109.69 ± 17.00 N; $P < 0.001$), which was in line with the hypothesis. This difference was not influenced by maturation status ($P = 0.167$). The small difference, observed in the first part of this study, may suggest isometric MVF could be important to youth soccer performance. In the second part of this study development of strength was considered by examining changes in MVF following an 8-wk. training period. It was found the elite group did not see an increase in MVF over time ($P = 0.723$). Collectively, these data suggest that elite youth soccer players possess slightly greater MVF, which may be a result of environmental or genetic factors. No further increase occurred following a period of training completed over 8-wk. This would seem to suggest that the current approaches to developing strength in this elite population might be sub-optimal though some caution must be exercised when using these data as a result of methodological limitations associated with the assessment of strength.

The small difference in MVF supports the hypothesis that elite youth soccer players would possess greater baseline MVF than non-elite counterparts. Two potential explanations for this are, adaptation as a result of repeated exposure to training and differences in genetic predisposition to strength. Should these findings be considered a result of adaptation to training, it is likely they are non-architectural adaptations (Schoenfeld 2010) brought about via long-term training exposure. Such adaptations, as with architectural ones, (both explained in more detail in Chapter 2) are brought about by sufficient mechanical stress disrupting normal muscular conditions to elicit these adaptations (Schoenfeld 2010). Typically, neural adaptations are responsible for increases in strength in pre-pubertal and novice athletes whereas those undergoing, or beyond, puberty also experience alterations to muscle architecture (Schoenfeld 2010; Marcotte et al. 2015). These proposed neural adaptations leading to increased MVF are potentially a result of the overall training undertaken leading to improved intra- and inter-muscular co-ordination. As data showed a different between cohorts not influenced by maturation status there is greater confidence in proposing potential adaptations were neural. It is proposed that architectural changes would have manifested as increased POST MVF, which did not occur. Future research should use greater sample sizes to consider separation of cohorts by age-group rather than maturation status. This may serve to determine specifically when such differences might occur. It is specifically postulated that younger groups may not have undertaken sufficient training to elicit such MVF increases, which may be traceable should such methodological considerations be made. Despite these ideas, it should be noted that the small differences seen in MVF could have been a result of learning effect in the IMTP. The reliability of strength tests in young populations has been discussed in the literature review of this thesis. An evaluation of the available data would seem to suggest that tests such as the IMTP can be reliable in these populations. It is however difficult to be fully confident that the data generated in this study from the IMTP was a “true” reflection of each individual’s ability to perform a maximal isometric action. Future studies should consider the reliability of this test specific to this population to be sure that any observed changes can be attributed correctly to change rather than error.

The potential influence of genetic predisposition should also be considered. It is likely however that a combination of training and the possession of a more favourable genetic profile associated with muscular strength in the elite cohort ultimately allows for elite athletic performance. When considering genetics specifically for example, greater incidence of the *ACTN3* R577X SNP RR genotype (as described in Chapter 2, Santiago et al. 2008) in the elite sample could lead to greater isometric MVF as seen in the presented data. Beyond the genetic influence over muscular strength predisposition, there is also widespread interest in the contribution of genetics to the inter-individual variability in adaptations to training (Erskine et al. 2014). From the presented results, it could be argued that elite youth soccer players may have predisposition for increased strength, increased trainability for strength or a combination. In Chapter 2 it was stated that Eynon *et al.* noted many polymorphisms of many genes influence elite athletic status (Eynon et al. 2013). It is for this reason that expansion of current knowledge of particular genes associated with strength would be advantageous in further understanding these data beyond these speculations. Of these explanations, it is likely that a mixture of genetic predisposition and an accumulation of training are responsible for the greater baseline MVF seen in the elite cohort.

An alternative explanation for the observed differences in the data may be related to the methodological approaches used in the investigation. It is accepted that conclusions from these data are only representative of the specific methodology employed in this investigation. The IMTP though, is considered a good test for multidirectional athletes due to the adopted body position being similar to one seen regularly in sports (Darrall-Jones et al. 2015). It could be considered that this may have resulted in a predisposition for increased performance in the elite group due to their time spent undertaking soccer training. This could in turn be seen as having potential to influence results. Irrespective of this, the IMTP is considered to offer useful information, especially in the practicalities of testing in the applied world. As a result, the baseline data from this study are considered to be novel and interesting. It must be kept in mind though that these data are only relevant to the soccer academy tested and that future studies might consider using different populations to increase the usability of these findings.

Having attributed the small differences in baseline strength to long-term training exposure, no further MVF increases following a further period of 8-wks. typical training were found. This is especially surprising in the POST elite group, many of whom were undertaking specific resistance training activities. It is considered this too could be a result of a number of factors. One such explanation could relate to the POST group being made up of some individuals who are in age group not participating in resistance training (e.g. U14). Future studies, with greater sample sizes, may look to analyse data by age group rather than maturation group to increase the sensitivity of such conclusions. It was also proposed in Chapter 4 that training completed may be insufficient to elicit adaptation to increase muscular strength may be supported by the data here. Drawing from evidence considering optimal, or previously successful interventions for increasing strength also in Chapter 2, a re-evaluation of strength training practices is recommended. Generally, this would include an earlier introduction and more frequent implementation of specific strength training (Lloyd et al. 2016). Such restructuring may lead to further neural adaptation, though it is thought this may allow architectural changes also. Future research could look to measure muscle architecture measures such as physiological cross sectional area to determine the success of such interventions. Such adaptations could subsequently lead to further MVF increases beyond those seen here.

For the first time, the IMTP has been used to determine greater baseline MVF data for English Premier League soccer academy players across U9 to U21 age groups compared to controls. Subsequently, no further effect of systematic training on MVF following 8-wks. training was seen. These data coupled with Chapter 3's findings seem to suggest that training specific to increasing strength may be initiated too late, be too infrequent and not be sufficiently focused on increasing strength to allow further increases during this 8-wk period. It is recommended that future work might investigate strength increases following training more aligned with LTAD Position

Statements. Investigation into genes and specific SNPs that may influence muscular strength and response to training to provide greater information on this elite population are also recommended. Practitioners might consider that although only a small difference in MVF was seen between groups, greater MVF would likely be advantageous for those hoping to progress from youth to senior elite soccer. It is recognised though that greater confidence in these data could be obtained via a thorough reliability study of the IMTP, using the appropriate sample. In conclusion, although it's programming should not come at the detriment of technical or tactical development, increased strength may be advantageous for performance purposes.

CHAPTER 5

NOS3 RS2070744 GENOTYPE IS ASSOCIATED WITH ELITE YOUTH SOCCER PLAYER STATUS BUT NOT WITH MAXIMUM ISOMETRIC STRENGTH

5.1 ABSTRACT

Aim It was investigated whether single nucleotide polymorphisms (SNPs) of the nitric oxide synthase 3 (*NOS3*, rs2070744), peroxisome proliferator-activated receptor alpha (*PPARA*, rs4253778), vitamin D receptor (*VDR*, rs2228570) and collagen, type I, alpha 1 (*COL1A1*, rs2249492) genes were associated with elite youth soccer status and isometric maximum voluntary force (MVF).

Methods Two-hundred-and-fifty-one elite youth soccer players (8-21 yrs.) and 115 maturation-matched controls were genotyped for the aforementioned SNPs. From these cohorts, 148 ESP and 93 CON performed an isometric mid-thigh pull MVF assessment.

Results The frequency distributions of the *NOS3* T-allele and TT genotype were higher in elite youth soccer (65.5 % and 45.0 %, respectively) compared to controls (54.8 % and 30.4 %, respectively; $P \leq 0.005$). However, there was no difference in allele or genotype frequency distribution between cohorts for the other three SNPs ($P \geq 0.057$). Furthermore, there were no genotype associations with MVF for any of the four SNPs ($P \geq 0.610$).

Conclusion Data suggest that the *NOS3* rs2070744 SNP may be important in determining elite youth soccer player status. However, as neither this or the other three SNPs were associated with MVF, the *NOS3* T-allele may influence other muscle phenotypes associated with elite youth soccer, such as muscle volume, power and speed of contraction.

5.2 INTRODUCTION

In Study 2, maximum voluntary force (MVF) was higher in elite youth soccer players (ESP) than an maturation-matched control group (CON). Therefore, in this chapter, it was investigated whether this may have been in part due to genetic variation.

There is strong evidence suggesting genetic influence on sporting ability is polygenic (Hughes et al. 2011; Ma et al. 2013; Ben-Zaken et al. 2013; Ahmetov et al. 2009; Eynon et al. 2013; Ruiz et al. 2010). Thus, in this study, the potential influence of four SNPs on MVF in ESP compared with CON was investigated. it was hypothesised SNPs of three genes would be associated with MVF via an influence on muscle hypertrophy (e.g. *NOS3, PPARA* and *VDR*), while a SNP of the *COL1A1* gene may exert its effect on MVF by influencing skeletal muscle force transmission.

The first of these genes, *NOS3,* encodes the enzyme endothelial NO synthase (eNOS), which synthesizes nitric oxide (NO) (Gómez-Gallego et al. 2009; Eynon et al. 2013). A SNP (-786 T/C, rs2070744) within this gene results in reduced gene promoter activity, which may decrease eNOS synthesis in the presence of the C-allele (Nakayama et al. 2000). Previously, associations have been made between this SNP and elite performance in power-oriented events (throwing, jumping, sprinting), with the *NOS3* -786 T-allele being more frequently distributed among elite power athletes (Gómez-Gallego et al. 2009). This is potentially due to the role NO plays in muscle hypertrophy as a result of its regulation of myoblast fusion via a cGMP-dependent induction of the BMP antagonist, follistatin (Long et al. 2006).

Another mechanism that may influence muscular hypertrophy involves peroxisome proliferator-activated receptor α (PPARα). PPARα is a transcription factor that regulates lipid, glucose, and energy homeostasis, and controls body weight and vascular inflammation (Desvergne & Wahli 1999). PPARα regulates the expression of genes involved in fatty acid utilization, in tissues such as skeletal muscle (Jamshidi 2002). Polymorphisms of the gene may lead to a metabolic advantage towards anaerobic metabolism (Petr et al. 2014; Proia et al. 2014). Previous studies have found the C-allele of the *PPARA* rs4253778 SNP to be associated with increased anaerobic performance and a higher composition of type II muscle fibres (Ahmetov et al. 2006), left ventricular growth in C-allele homozygotes (Jamshidi 2002) and greater muscle mass and explosive strength in Lithuanian athletes (age 22.0 ± 6.3 yrs., Ginevičienė et al. 2010). Although these findings could lead to increased muscular strength it remains to be seen if such associations are seen in elite youth soccer.

Vitamin D also has a potential role in affecting strength by mediating myoblast proliferation, differentiation and migration, which aids hypertrophy as a response to exercise stimuli (Osman et al. 2015; Wang et al. 2015). It has also been observed that optimal vitamin D status is associated with greater muscle contraction, potentially leading to increased force production (Owens et al. 2016). The *VDR* gene has been associated with the concentration of vitamin D in tissues (Geusens et al. 1997; Demay 2006; Uitterlinden et al. 2004). Furthermore, maximum isometric and concentric strength were previously associated with *VDR* rs10735810 in those with chronic obstructive pulmonary disease (Hopkinson et al. 2008) and untrained men and women of > 60 yrs. with reference to *VDR* rs2228570 (Windelinckx et al. 2007), suggesting that other SNPs in the *VDR* gene, such as rs2228570 may be associated with MVF in elite youth soccer players.

Beyond the SNPs described above that may influence muscular strength via their influence on muscular hypertrophy, additional SNPs may affect strength by influencing force transmission. The main structural component of bone, tendons and ligaments, and a component of muscle, is type I collagen. The α1 chain is encoded by the *COL1A1* gene (Collins et al. 2010; Hu et al. 2011). Collagenous tissue within the muscle-tendon unit (such as the extra-cellular matrix, the perimysium, the endomysium, the aponeuroses and the tendon) transmits force, both longitudinally and laterally (Huijing 1999). Previously, *COL1A1* SNPs (rs1107946 and rs2412298, Garcia-Giralt et al. 2002) have been shown to influence gene expression, leading to differences in bone mineral density. Due to the similarities in composition of bone and tendon, such variations have also been proposed to potentially affect MVF (van Pottelbergh et al. 2001). Mechanical stimuli via muscle contraction may cause increased collagen gene expression leading to increased muscle collagen protein synthesis (CPS, Buchanan & Marsh 2002; Moore et al. 2005). Jones *et al.* first proposed such stimuli may lead to increased MVF, via increased connective tissue attachments, effectively dividing the muscle into multiple force-generating units, thus increasing overall force potential without increasing muscle size (Jones et al. 1989). This idea is reinforced when coupled with the notion that force transmission occurs both longitudinally and laterally via such attachments to the surrounding matrix of connective tissue (Street 1983). Therefore, it was postulated that the rs2249492 SNP of this gene may influence MVF by enhancing muscle specific force, i.e. the maximum force per unit physiological cross-sectional area of muscle (Erskine et al. 2011). Further information on these genes is presented in Chapter 2.

The aims of this study were two-fold: (i) to investigate differences in genotype/allele frequency distribution of the *NOS3* rs2070744, *PPARA* rs4253778, *VDR* rs2228570 and *COL1A1* rs2249492 SNPs between ESP and CON; and (ii) to examine associations between isometric MVF and the aforementioned SNPs in ESP and CON. It was hypothesised that a greater frequency of potentially preferential genotypes for greater MVF would be observed in ESP. It was also hypothesised that this would lead to an association between these favourable genotypes and increased MVF.

5.3 METHODS

Participants

An initial total cohort of 251 ESP from U9 to U21 age groups and 115 maturation-matched CON participants volunteered to take part in this study. Elite participants were defined by their involvement in systematic training with a youth soccer academy of an English Premier League soccer club. Control participants took part only in school physical education lessons and recreational level sport/play. Of that total cohort one hundred and forty-eight elite ESP and 93 CON undertook isometric strength testing [see Table 5.1 for participant information]. The study conformed to the Declaration of Helsinki, was approved by the Institutional Ethics Committee and consent was obtained from all participants/parents/guardians where appropriate.

Table 5.1 Participant characteristics for those who undertook isometric mid-thigh pull testing.

Group	Maturation Group (*n*)	Age (years ± S.D.)	Stature (m ± S.D.)	Body Mass (kg ± S.D.)
Elite	Pre-PHV (84)	11.0 ± 1.5	1.45 ± 0.08	36.6 ± 5.8
	Mid-PHV (12)	14.1 ± 0.5	1.61 ± 0.07	48.6 ± 5.9
	Post-PHV (52)	16.8 ± 1.7	1.79 ± 0.06	69.0 ± 8.5
Control	Pre-PHV (44)	11.2 ± 1.3	1.45 ± 0.08	37.5 ± 5.8
	Mid-PHV (15)	13.7 ± 0.6	1.63 ± 0.05	51.2 ± 8.1
	Post-PHV (34)	16.2 ± 1.8	1.75 ± 0.05	67.1 ± 9.3

Isometric mid-thigh pull strength test

A full explanation of the procedural information for this test is presented in Chapter 4.

Saliva sampling

In order to collect genetic information, two-hundred-and-eighty-two participants (188 ESP and 94 CON) each provided a 2-ml saliva sample, collected into specialised saliva collection tubes (Isohelix, Kent, U.K) after at least 30 min of not ingesting food, liquid or chewing gum. Participants were instructed to dribble their saliva into the tube until it reached a 2 mL indicator line. After collection, the tubes were gently shaken to mix the saliva with 2 mL of non-toxic stabilization buffer contained within the tube and were incubated for 60 min at 56°C prior to aliquotting into 2 mL cryotubes (Eppendorf AG, Hamburg, Germany). The saliva samples were then stored at -80°C until subsequent analysis.

Whole blood sampling

The remaining eighty-four participants (63 ESP, 21 CON) had 10-ml blood samples drawn into 10-ml EDTA tubes (BD Vacutainer Systems, Plymouth, UK) from a superficial forearm vein. The whole blood was aliquotted into 2-ml tubes (Eppendorf AG, Hamburg, Germany) and stored at -80°C until subsequent analysis.

DNA extraction and determination of NOS3 rs2070744, *PPARA* rs4253778, *COL1A1* rs2249492 and *VDR* rs2228570 genotypes*.*

For DNA extraction from whole blood and saliva samples, 20 μL proteinase K (Qiagen, Hilden, Germany) was pipetted into a 1.5 mL microcentrifuge tube. 200 μL of sample and 200 μL of lysis buffer (AL, Qiagen, Hilden, Germany) was then added and vortexed for 15 s. this was then incubated at 56°C for 10 mins to maximise DNA yield. Following incubation, 200-µL ethanol (96-100%) was added to the sample and vortexed for 15 s. This mixture was then transferred to a QIAamp Mini spin column (Qiagen, Hilden, Germany) within a 2 mL collection tube. This was then centrifuged at 8000 rpm for 1 min before the mini spin column was transferred to a clean 2 mL collection tube. To the column 500 *µ*L binding buffer (AW1, Qiagen, Hilden, Germany) was then added before being centrifuged again at 8000 rpm for 1 min. The column was again place into a clean 2 mL collection tube and 500 *µ*L wash buffer (AW2, Qiagen, Hilden, Germany) was added before centrifuging at 14 000 RPM for 3 min. The column was then placed into a clean 2 mL collection tube and centrifuged at 14 000 RPM for 1 min. Finally, the spin column was placed in a clean 1.5 mL microcentrifuge tube, 200 *µ*L wash buffer (AE, Qiagen, Hilden, Germany) was added to the column and was centrifuged at 8000 RPM for 1 min following 1 min incubation at room temperature.

Real-time polymerase chain reaction (RT-PCR) was performed to determine the genotype of the *NOS3* rs2070744, *PPARA rs*4253778, *VDR* rs 2228570 and *COL1A1* rs2249492 polymorphisms for each participant. Each 10-µl reaction volume contained 5 *µ*L Genotyping Master Mix (Applied Biosystems, Foster City, USA), 3.5 *µ*L nuclease-free H_2O (Qiagen, Hilden, Germany), 0.5 *µ*L custom-made SNP genotyping assay (Applied Biosystems, Foster City, USA), plus 1 *µ*L sample DNA. For control reaction volumes, 1*µ*L nuclease-free H_2O (Qiagen, Hilden, Germany) replaced the DNA template. RT-PCR was performed (Rotor-Gene Q, Qiagen, Hilden, Germany) using the following protocol: denaturation at 95°C for 10 min, followed by 50 cycles of incubation at 92°C for 15 s and annealing and extension at 60°C for 1 min. Genotypes were ultimately determined using Rotor-Gene Q Pure Detection 2.1.0 software (Qiagen, Hilden, Germany). All samples were analysed in duplicate and in all cases there was 100% agreement between genotype for samples from the same participant.

Genotyping was performed in accordance with published genotyping and quality control recommendations (Chanock *et al.,* 2007). These included describing genotyping assays and protocols in detail, producing an overview of sample ID and well number before genotyping, incorporating internal controls by genotyping samples in duplicate (from the same DNA collection), comparing current genotype frequencies with previously published frequencies in a similar population, and evaluating the level of agreement with the Hardy-Weinberg principle.

Statistical analysis

Genotype frequencies of all participants were tested for compatibility with Hardy-Weinberg equilibrium (HWE) using chi-square (χ^2) tests. For each SNP, genotype and allele frequency distribution differences between ESP and CON were assessed using Pearson χ^2 tests. Three-way between-group ANOVAs were used to investigate the main effect of athlete status (ESP *vs.* CON); the main effect of maturation stage (pre *vs.* post PHV); the main effect of genotype (three groups); the interaction between athlete status, maturation stage and genotype; the interaction between athlete status and genotype; the interaction between maturation stage and genotype; and the interaction between athlete status and maturation stage. Due to low numbers in ESP and CON MID PHV groups, these data were excluded from statistical analysis for genotype frequency distribution and maximum voluntary force (MVF) comparisons between genotype and maturation groups. Maximum voluntary force was allometrically scaled as previously described in this thesis. Data are presented as mean ± standard deviation unless otherwise stated and statistical significance was accepted at $P < 0.05$.

5.4 RESULTS

Hardy-Weinberg Equilibrium (HWE)

The genotype frequency distributions for *PPARA* rs4253778 (ESP: χ^2 = 1.405, *P* = 0.495; CON: χ^2 = 5.720, *P* = 0.057), *NOS3* rs2070744 (ESP: χ^2 = 2.084, *P* = 0.353; CON: χ^2 = 0.035, *P* = 0.983), *COL1A1* rs2249492 (ESP: χ^2 = 0.001, *P* = 1.000; CON: χ^2 = 0.470, *P* = 0.791) and *VDR* rs2228570 (ESP: χ^2 = 0.918, *P* = 0.632; CON: χ^2 = 0.068, *P* = 0.966) were all in HWE.

Allele and genotype frequency distribution in elite soccer players and control participants

The allele frequency distribution of the *NOS3* rs2070744 SNP differed between elite soccer players (T-allele 65.5 %) and control participants (T-allele 54.8 %, χ^2 = 7.757, *P* = 0.005). However, for *PPARA* rs4253778 (χ^2 = 0.154, *P* = 0.695), *COL1A1* rs2249492 (χ^2 = 0.271, *P* = 0.603) and *VDR* rs2228570 (χ^2 = 0.264, *P* = 0.607), the allele frequency distributions did not differ between ESP and CON.

For the total cohort (*n* = 366), the genotype frequency distribution of the *NOS3* rs2070744 SNP differed between ESP (TT genotype 45.0 %) and CON (TT genotype 30.4 %, χ^2 = 26.486, *P* < 0.001; Figure 5.1). However, for *PPARA* rs4253778 (χ^2 = 5.773, *P* = 0.057), *COL1A1* rs2249492 (χ^2 = 0.170, *P* = 0.427) and *VDR* rs2228570 (χ^2 = 1.238, *P* = 0.539; Figure 5.1), the genotype frequency distributions did not differ between ESP and CON.

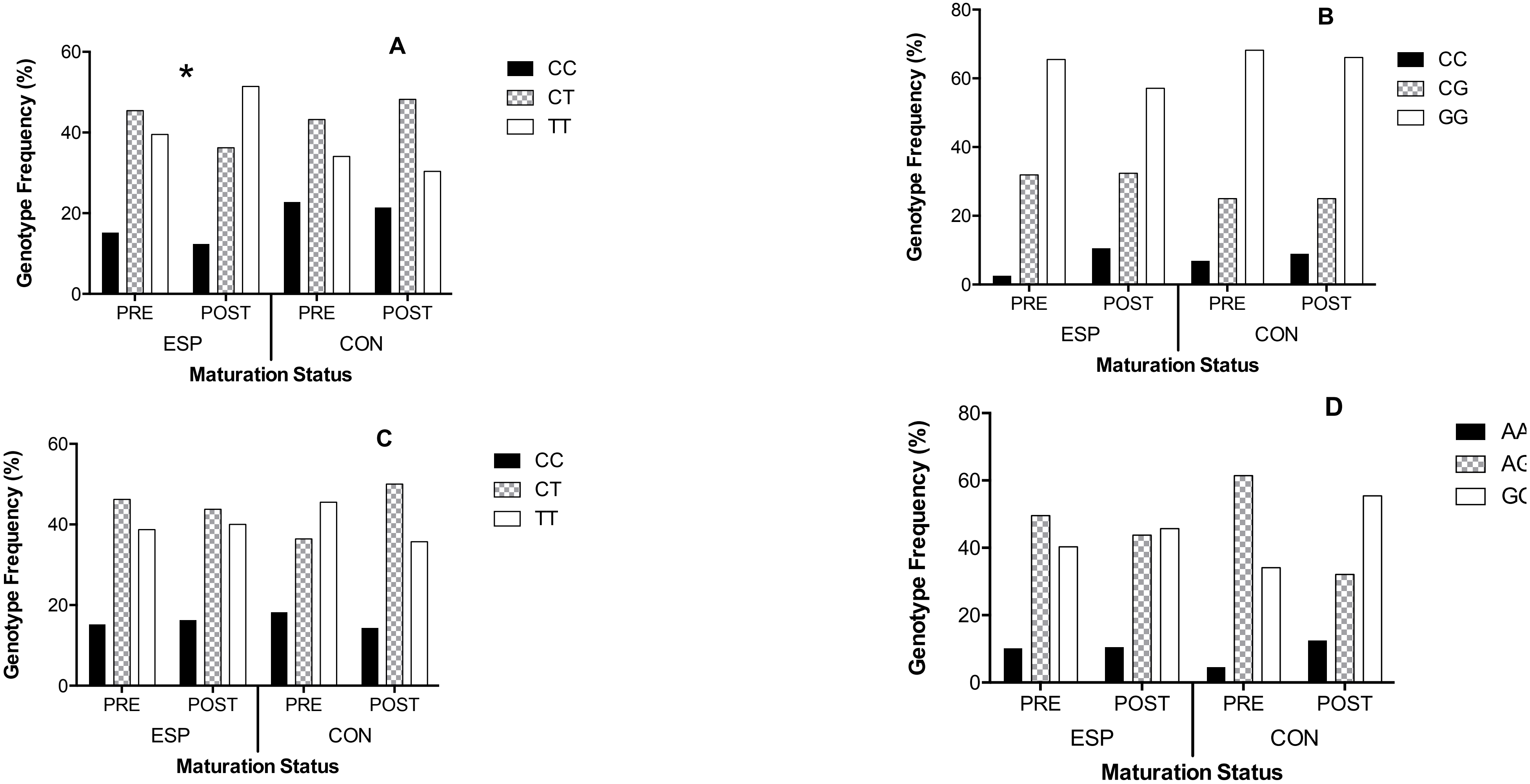


Figure 5.1 Genotype frequency distributions for the (A) *NOS3* rs2070744, (B) *PPARA* rs4253778, (C) *COL1A1* rs2249492 and (D) *VDR* rs2228570 SNPs in elite youth soccer players (ESP) and control participants (CON). * $P < 0.001$, significantly different from CON genotype frequency distribution.

The interaction effect between genotype, athlete status and maturation status on MVF

NOS3 rs2070744

There was a main effect for maturation (F (1, 202) = 251.56, $P < 0.001$), with the POST-PHV group producing greater MVF than the PRE-PHV group (137.45 ± 20.77 *vs*. 97.95 ± 13.19 N, respectively, Figure 5.2). There was no main effect for genotype (F (2, 202) = 0.495, $P = 0.610$) or athlete status (F (1, 202) = 3.338, $P = 0.069$). There was no two-way interaction between genotype and maturation (F (2, 202) = 0.146, $P = 0.864$), genotype and athlete status (F (2, 202) = 1.727, $P = 0.180$) or maturation status and athlete status (F (1, 202) = 2.971, $P = 0.086$). There was also no three-way interaction for genotype, maturation and athlete status (F (2, 202) = 0.421, $P = 0.657$).

PPARA rs4253778

There was a main effect for maturation (F (1, 202) = 136.40, $P < 0.001$), with the POST-PHV group producing greater MVF than the PRE-PHV group (137.45 ± 20.77 *vs*. 97.95 ± 13.19 N, respectively, Figure 5.2). There was no main effect for genotype (F (2, 202) = 0.008, $P = 0.992$) or athlete status (F (1, 202) = 1.872, $P = 0.173$). There was no two-way interaction between genotype and maturation (F (2, 202) = 0.011, $P = 0.989$), genotype and athlete status (F (2, 202) = 0.318, $P = 0.728$) or maturation status and athlete status (F (1, 202) = 0.881, $P = 0.349$). There was also no three-way interaction between genotype, maturation and athlete status (*F* (2, 202) = 0.040, *P* = 0.961).

COL1A1 rs2249492

There was a main effect for maturation (*F* (1, 202) = 229.15, *P* < 0.001), with the POST-PHV group producing greater MVF than the PRE-PHV group (137.45 ± 20.77 *vs*. 97.95 ± 13.19 N, respectively, Figure 5.2) and athlete status (*F* (1, 202) = 6.945, *P* = 0.009) with the ESP producing greater MVF than the CON (115.53 ± 22.68 *vs*. 110.8 ± 29.83 N, respectively). There was no main effect for genotype (*F* (2, 202) = 0.230, *P* = 0.795). There was no two-way interaction between genotype and maturation (*F* (2, 202) = 0.100, *P* = 0.905), genotype and athlete status (*F* (2, 202) = 0.315, *P* = 0.730) or maturation status and athlete status (*F* (1, 202) = 1.040, *P* = 0.309). There was also no three-way interaction for genotype, maturation and athlete status (*F* (2, 202) = 0.241, *P* = 0.786).

VDR rs2228570

There was a main effect for maturation (*F* (1, 202) = 123.01, *P* < 0.001), with the POST-PHV group producing greater MVF than the PRE-PHV group (137.45 ± 20.77 *vs*. 97.95 ± 13.19 N, respectively, Figure 5.2) and athlete status (*F* (1, 202) = 4.565, *P* = 0.034), with the ESP producing greater MVF than the CON (115.53 ± 22.68 and 110.8 ± 29.83 N respectively). There was no main effect for genotype (*F* (2, 202) = 0.204, *P* = 0.816). There was no two-way interaction between genotype and maturation (*F* (2, 202) = 1.763, *P*

= 0.174), genotype and athlete status (F (2, 202) = 0.956, P = 0.386) or maturation status and athlete status (F (1, 202) = 0.680, P = 0.410). There was also no three-way interaction for genotype, maturation and athlete status (F (2, 202) = 0.003, P = 0.997).

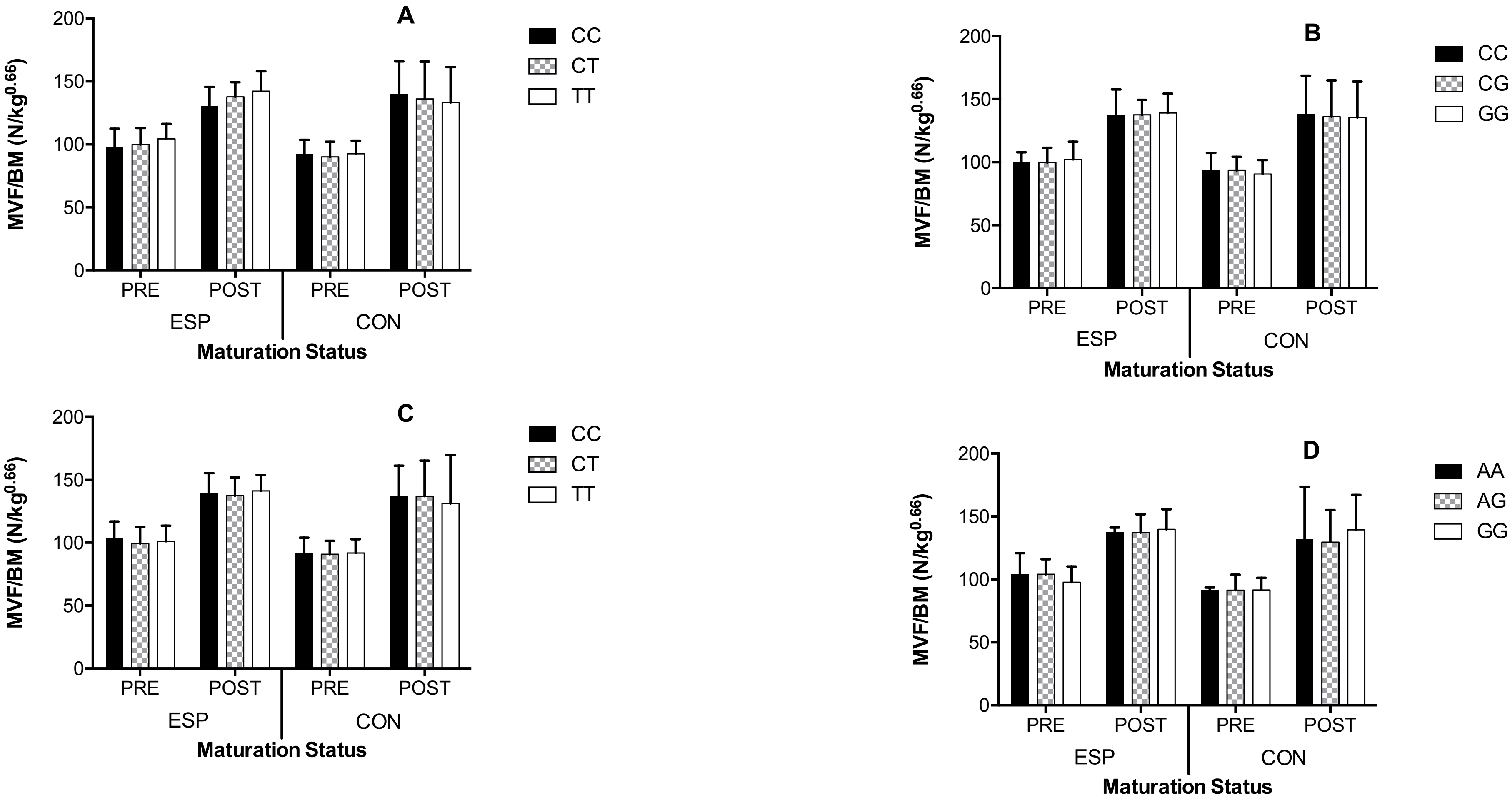


Figure 5.2 Isometric maximum voluntary force (MVF) normalised to body mass (BM) for the (A) *NOS3* rs2070744, (B) *PPARA* rs4253778, (C) *COL1A1* rs2249492 and (D) *VDR* rs2228570 SNPs in elite youth soccer players (ESP) and control participants (CON).

5.5 DISCUSSION

It was investigated whether the genotype and allele frequency distributions of the *NOS3* rs2070744, *PPARA* rs4253778, *VDR* rs2228570 and *COL1A* rs2249492 SNPs differed between an elite youth soccer cohort and control group. It was also examined whether genotype differences were associated with isometric MVF. It was hypothesised that potentially 'favourable' genotypes with regard to maximum strength/power (proposed either in the literature or within the current study) would be more prevalent in elite soccer players, which would result in an interaction between genotype and cohort (for MVF). As maturation status may have confounded any genotype interaction with athlete status on MVF, cohorts were stratified according to peak height velocity (PHV), i.e. pre-, mid- and post-PHV. It was subsequently hypothesised that the favourable genotype for each SNP would be more prevalent in the post-PHV group of the elite soccer players (as strength may play a greater role in elite soccer after puberty). It was also proposed that those possessing the favourable genotype in this group would demonstrate greater MVF than all other groups, i.e. a three-way interaction between cohort, maturation and genotype. It was found that *NOS3* rs2070744 genotype and allele frequency distributions differed between cohorts, with 45.0 % of the elite group possessing the favourable TT genotype compared to 30.4 % in the control group, while 65.5 % of the elite soccer players possessed the favourable T-allele compared to 54.8 % in the control group. However, no associations were seen between any of the investigated SNPs and isometric MVF in either cohort. This may suggest no predisposition for strength in elite youth soccer players based on the SNPs examined, though could be explained by age limiting the potential for increased strength manifestation.

NOS3 rs2070744 TT genotype frequency distribution has previously been found to be significantly higher in power athletes (57 %) than in endurance athletes (33 %) or a control group (34 %) (Gómez-Gallego et al. 2009). This was found to be in line with the findings of this study. The frequency of the T-allele has also been found to be higher in power athletes (71 %) than in endurance (55 %) and control counterparts (56 %) (Gómez-Gallego et al. 2009). The mechanism by which this SNP might benefit power performance is unclear, although it may relate to the role NO is thought to play in muscle hypertrophy during training adaptation (Gómez-Gallego et al. 2009). As NO is involved in myoblast proliferation and fusion, it is thought this may be the mechanism by which similar stimulation of hypertrophy has been seen previously via supplementation with the semi-essential amino acid L-arginine (the substrate for endogenous synthesis of NO) (Long et al. 2006). This is supported by the finding that maintenance of exercise-stimulated NO signalling mechanisms is necessary to attenuate human skeletal muscle atrophy (Salanova et al. 2008).

Although soccer cannot be described as a strength-based sport *per se*, the repetitive powerful actions required (Murtagh et al., unpublished data) might explain why a larger number of individuals in the elite cohort possessed the preferential *NOS3* rs2070744 'power' genotype/allele compared to the control group. The higher T-allele and TT genotype frequencies in ESP could suggest they have larger muscles as a result of the SNP's proposed effect on hypertrophy, which future studies may look to measure. However, this SNP was not associated with MVF, despite MVF being higher in ESP than CON (please refer to chapter 2). This may be related to the associations between this SNP and power (Gómez-Gallego et al. 2009), rather than maximum strength. The force output of a maximally activated muscle is dependent upon the muscle cross-sectional area (CSA), while muscle fibre length (independently of fibre-type) is the primary determinant of contraction velocity (Jones et al. 1989). As power is the product of force x velocity, and muscle volume is the product of muscle CSA x muscle fibre length (Jones et al., 1988), it follows that muscle volume is the main determinant of muscle power (Jones et al., 1988). Thus, the *NOS3* association with the elite youth soccer cohort could be due to this SNP influencing muscle volume, and therefore power, rather than muscle CSA and MVF (thus explaining why no association between this SNP and MVF were seen). Indeed, unpublished data from our laboratory confirms that muscle volume from a sub-sample (U18 - 21 year groups) of the elite cohort was larger than in an maturation-matched group of recreational soccer players (Murtagh *et al.*, unpublished data). It would be interesting to investigate whether this SNP was associated with muscle volume and power in elite youth soccer players.

Despite the hypothesis that the *PPARA* rs4253778 C-allele would be associated with greater MVF in the ESP (due to previous findings associating it with greater left ventricular mass possible due to increased *PPARA* expression (Jamshidi 2002)), no association was found between this SNP and

MVF. Previous investigation into allele frequency found the frequency of the *PPARA* C-allele (26.3 % vs. 17.2 %) was significantly higher in Lithuanian power-oriented athletes and athletes with mixed aerobic/anaerobic activity (*n* = 80) in comparison with 250 controls (Gineviciene et al. 2014). Results from this study showed the frequency of the *PPARA* C-allele to be 21.7 % and 20.4 % in the elite and control cohorts, respectively. However, the *PPARA* C-allele frequency distribution was even greater in the POST ESP group (26.7 %), which is not dissimilar to 24.3 % found in senior professional top-flight Russian soccer players (Egorova et al. 2014). In youth soccer, especially in the pre-pubertal phase, muscular strength and its subsequent phenotypic attributes may be less important than soccer technique, due to differences in muscle size being less pronounced in pre-pubertal players. However, boys and girls (11.0 ± 0.4 yrs.) with the *PPARA* C-allele demonstrated greater handgrip strength than GG homozygotes (Ahmetov et al. 2013). Thus, the importance of this SNP in determining maximal strength in young people is still unclear, although with the IMTP assessment (a more functional strength measurement in elite youth soccer than handgrip strength); it does not appear to have any effect.

Polymorphisms of the *VDR* gene have previously been found to mediate the amount of vitamin D entering tissues. This in turn regulates the effect of the hormone (Geusens et al. 1997; Windelinckx et al. 2007; Demay 2006; Uitterlinden et al. 2004). Vitamin D appears to affect muscle strength by mediating myoblast proliferation, differentiation and migration (Osman et al. 2015; Wang et al. 2015), which leads to increased muscle size during skeletal muscle regeneration (Saini et al. 2009). In the present study, there was no difference in the *VDR* rs2228570 allele or genotype frequency distribution between elite and control cohorts. There are few studies stating the observed frequency of genotypes for this SNP though Osman *et al.* (2015) found the AA genotype and A-allele to have frequencies of 38 % and 48.04 % in healthy Emirati population (Osman et al. 2015). This is far greater than observed in both ESP and CON. Previous studies have shown that both isometric and concentric strength of the quadriceps were influenced by *VDR* genotypes (Windelinckx et al. 2007; Hopkinson et al. 2008), though no such association with isometric MVF was found here. Bozsodi *et al.* also looked at four different *VDR* SNPs (rs4516035, rs1544410, rs731236 and rs10783215) and found associations with handgrip strength in 706 male and female schoolchildren (9.8 ± 1.2 yrs., Bozsodi et al. 2016). These findings would suggest that *VDR* variants do have associations with muscular strength. There is potential that no such associations were observed, as the IMTP requires a degree of inter-muscular co-ordination and the studies above typically incorporated only one muscle group or joint. This influence of co-ordination may obscure genetic influences on muscle force generating capacity that would otherwise be seen in simpler (single joint) strength tests. As *VDR* SNP has not been examined previously for associations with this phenotype, either in elite soccer players or in a non-athlete cohort the value of investigating it here is considered appropriate.

Beyond the three genes investigated that may play a role in muscular hypertrophy, *COL1A1* may have associations via its affect on force transmission. No difference was found though between elite soccer players and control participants regarding genotype or allele frequency distribution of the *COL1A1* rs2249492 SNP, and no association between this SNP and isometric MVF. As far as is known, this is the first study to investigate this SNP in relation to elite youth soccer player status and MVF. Previously, one study found an association between a different SNP (Sp1) *COL1A1* with indices of upper limb muscle strength in community-dwelling ambulatory men over age 70 years (van Pottelbergh et al. 2001). Beyond the fact that skeletal muscle and tendons contain type I collagen fibres, they were unable to postulate as to how the *COL1A1* Sp1 genotype affected muscle strength. It is possible that if SNPs have a role in collagen synthesis (leading to structural changes in the muscle), this may lead to increased muscular strength (Drew et al. 2012; Buchanan & Marsh 2002; Kjaer et al. 2005; Magnusson et al. 2007). This may occur as increased intra- and inter-muscular collagen/extracellular matrix may causes an increase in the transmission of force in the lateral direction, thus increasing overall force output (Jones et al. 1989; Huijing 1999; Kjaer et al. 2005). As the study by van Pottelbergh *et al.* found an association between *COL1A1* and muscular strength in men over 70 years, there is potential that the favourable genotype may lead to phenotypic advantages only seen in individuals older than those measured here. This may be as with advancing age comes an increase in intra- and inter-muscular connective tissue (Huijing 1999).

Limitations of this study came mainly from the relatively small frequency distributions of certain genotypes, as a result of cohort separation into groups and sub-groups. Specifically, there were small frequency distributions of the *PPARA* rs4253778 CC genotype in ESP PRE (n = 3) and CON PRE (n = 3) and POST (n = 5) and *VDR* rs2228570 CON PRE (n = 2). Also, it is difficult to draw conclusions on phenotype based on genotype in soccer, due to different player positions requiring different physiological demands, especially at an elite level. For example, a top-level central-midfielder may have a far greater aerobic capacity than a world-class full back, who is likely to have a better speed/power profile. However, beyond the novelty of investigating associations between these four SNPs with a reproducible MVF measure, the strength of this study is considered to come from using elite level youth soccer players at different stages of maturation, and comparing them with a control cohort. The benefits however are seen in future studies expanding cohort size (perhaps by using multiple academies) to address some of these limitations. As previously eluded to in the literature review of this thesis, the genotyping of children should not be done to aid talent identification in elite sport. This type of data should rather be taken as an opportunity to enable a greater understanding of the type of genetic profiles that may contribute to elite soccer success to be established. It should also be clearly stated that the genetic makeup of an individual cannot be solely responsible for their sporting performance as a range of other factors interact to determine performance. These data are though potentially useful as they may lead to bespoke considerations that may facilitate performance such as ideas around the individualisation of training to aid injury prevention and subsequently performance.

In conclusion, the TT genotype and T-allele of the *NOS3* rs2070744 SNP was more prevalent in elite youth soccer players than in a control group, though no genotype or allele differences were seen regarding the *PPARA* rs4253778, *VDR* rs2228570 or *COL1A1* rs2249492 SNPs. No associations between any of the examined SNPs and MVF when tested via IMTP were seen. Therefore, the *NOS3* T-allele may be important in determining elite youth soccer player status though perhaps not by influencing maximum isometric strength. It is proposed that it may, however, be influencing other muscle phenotypes associated with elite soccer, such as muscle volume and power. Further work is required to identify which gene variants may help explain the difference in strength between elite youth soccer players and maturation-matched control participants.

CHAPTER 6

SYNTHESIS

The purpose of this chapter is to provide a conceptual interpretation of the findings in relation to the original aims and objectives of this thesis. This section will also attempt to provide some practical recommendations around programming for muscular strength development in elite youth soccer players based on the information collected as a consequence of this thesis. This section will also include some discussion around limitations and advantages of "real world" research models. It will conclude by presenting recommendations of potential areas for future research.

6.1 ACHIEVEMENT OF AIMS AND OBJECTIVES

The aim of this thesis was to investigate the importance of strength in elite youth soccer performance. It was hoped the conclusions might provide practical greater knowledge around training practices and the resultant isometric strength levels, as well as improving existing knowledge on the genetics of strength in this population. This aim was achieved via the completion of three objectives.

Objective 1: investigate the amount of training undertaken by elite youth soccer players with attention paid to the distribution of different training types

This objective was addressed via the completion of Study 1 (Chapter 3). No studies have previously reported the duration and distribution of training types across all academy age groups in elite youth soccer. It was hoped this information could help to determine patterns in training of different academy phases. It was also thought this information may prove useful in the programming of training pertaining to increases in muscular strength. Duration of on-field soccer training, soccer match play, resistance training and non-resistance training athletic development were recorded for all players from U9 to U21 age groups over an 8-wk period. Total training time progressively increased between the U9 (268 ± 25 min/wk.) and U14 (477 ± 19 min/wk.) groups with the majority of training time (96.5 ± 3.9 %) consisting of soccer training and matches. Total training time then reduced from U14 to U15 (266 ± 77 min/wk.) groups, with no differences in training time between U15 and U21 (*P* ranged from 0.262 to 0.887). Only U15 to U21 players completed specific resistance training though no difference in session duration was seen between groups (*P* ranged from 0.247 to 0.626). The inclusion of resistance training coincided with a reduction in soccer training and match play when compared to time spent in these activities for younger groups (73.8 ± 3.2 % of total training). It is thought that the trends seen here represent a focus on technical and tactical improvement from U9 to U14 before the idea of physical periodisation is introduced at U15. Although, it is acknowledged that a limitation of this study is that using duration as a proxy measure for intensity, RPE load is difficult to implement in age groups unfamiliar with the method. It was concluded that data suggest the majority of training time is focused on technical development in elite youth soccer. As chronological age increases, there is a diversification of activities and a reduction in total training time. Such data may be useful in examining talent development strategies in soccer.

Objective 2: investigate the effectiveness of current training programmes completed by elite youth soccer players in increasing isometric maximum voluntary force production

This objective was addressed via the completion of Study 2 part A and B (both presented in Chapter 5). Previously there has been no normative data on baseline strength of elite youth soccer players across all age groups. It was therefore hoped data from Study 2 part A would provide a benchmark of strength as well as providing information on strength differences between populations. Under 9s to U21s performed an IMTP, as did an age and anthropometrically matched control group. A small increase was seen in isometric MVF in the elites compared to control group (118.29 ± 13.47 compared to 109.69 ± 17.00 N, $P < 0.001$). The data suggest elite youth soccer players do not possess considerably greater isometric strength than non-elite counterparts as hypothesised. Although it is a limitation of this study that it is unknown if/what level of strength training the control group undertook prior to this testing, it is considered unlikely that their total training would have matched the elite group. It is for this reason these data are considered useful, as they allow questioning of whether muscular strength is less important than first thought or whether findings relate to programming.

Having established baseline MVF data, Study 2 part B looked to determine the effects of eight further weeks training on isometric MVF in the elite group.

This was established by following the same testing protocol 8-wks. post-baseline. Following this period there was no difference seen in isometric MVF between groups (P = 0.167). It was hypothesised that this period of training would elicit increases in isometric MVF, though this did not occur. It is postulated training frequency and type throughout the academy provided insufficient stimuli to cause the morphological or neurological adaptation required for strength increases. This information suggests the programming presented in Chapter 3 should be adapted if increases in strength are desired.

Objective 3: investigate whether specific gene variations are associated with elite youth soccer player status and/or with maximum isometric voluntary force (MVF) production

This objective was addressed via the completion of Study 3 (Chapter 6). It was examined, for the first time, four SNPs, that may have associations with muscular strength as a result of their varied mechanisms. It was investigated whether *PPARA* rs4253778, *NOS3* rs2070744, *COLIA1* rs2249492 and *VDR* rs2228570 were associated with isometric MVF in elite youth soccer players. Genotype and allele frequency were determined for all four SNPs and compared between groups and within different maturation groups. Genotype and allele data was then analysed for association with corresponding participant's IMTP. *NOS3* allele and genotype frequency distribution significantly differed between cohorts ($P \leq 0.005$) though this was not seen in any other SNP for genotype ($P \geq 0.603$) or allele ($P \geq 0.057$). There were no genotype associations with MVF for any measured SNPs ($P \geq 0.610$). It is proposed that the absence of associations between MVF and *PPARA* rs4253778, *NOS3* rs2070744, *VDR* rs2228570 and *COL1A1* rs2249492 genotype is a reflection of these players not being predisposed for strength via utilisation of the mechanisms they affect. Consequently, though examination of other SNPs may be useful, appropriate strength training programming is important in increasing muscular strength in the population investigated here.

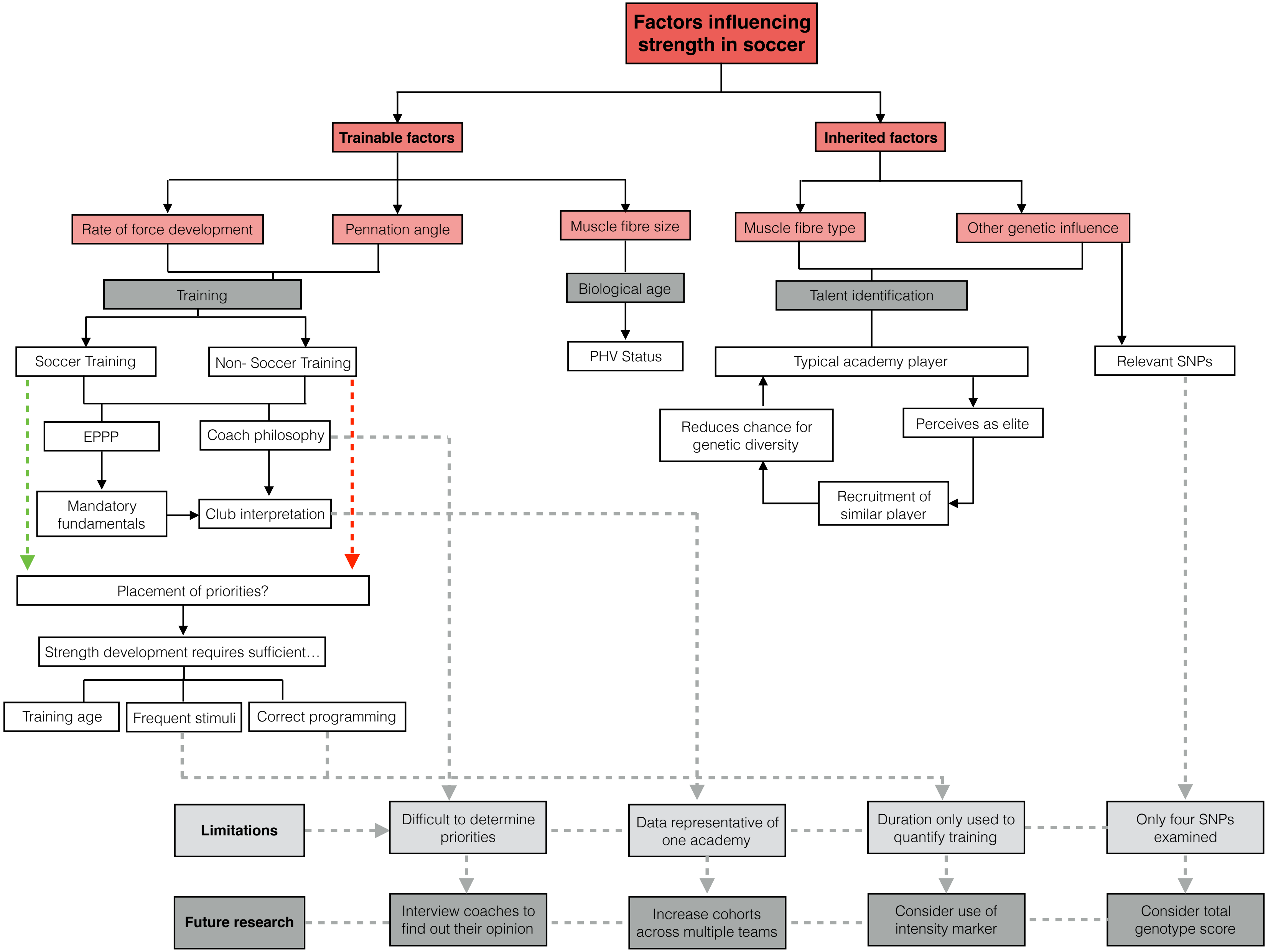
6.2 GENERAL DISCUSSION

One of the main goals of an elite soccer academy is the production and preparation of players for its senior first team. Soccer is a sport requiring the development of a diverse set of competencies across technical, tactical, psychological and physical attributes (Stølen et al. 2005). The training undertaken to maximise this outcome must be systematic and suitable to the training- and biological-ages of those participating (Lloyd et al. 2016). Within this thesis the physical side of the training matrix with specific attention afforded to the development of muscular strength was considered. This area of research was considered important due to the importance of muscular strength in underpinning powerful actions (such as speed (Christou et al. 2006), jumping ability (Comfort et al. 2014) and change of direction ability (Keiner et al. 2014)) that seem important in determining match results (Faude et al. 2012). Increases in muscular strength may also potentially lead to reductions in injury incidence (Zouita, Zouita, et al. 2016). This too is important for performance, as avoiding injury and increasing training and match availability must be achieved before consideration of optimising training adaptation.

The outcomes of this thesis were hoped to attempt to enable production of practical guidelines to aid practitioners in understanding and developing strength in this population. Figure 6.1 represents the attempt to graphically summarise the findings of the thesis within the broader framework of strength and soccer. Strength in soccer is dependent on two potential groups of factors, those that are trainable and those that may be inherited. Trainable factors, such as muscle fibre size (Ahtiainen et al. 2003; Phillips 2014; Schoenfeld 2010), pennation angle (Seynnes et al. 2007; Jones et al. 1989) and neural activation (Jones et al. 1989; Aagaard et al. 2002; Mikkola et al. 2007) have been widely reported in the literature to be enhanced by appropriate training. Heritable factors, such as genetic factors underpinning the potential for increased strength (Ahmetov et al. 2013) or adaptability to strength training (Thompson et al. 2004) have also been well reported.

Any inherited strength properties may play a crucial role in elite youth soccer via the talent identification process. Uncertainty about the processes associated with talent identification mean that only speculation can be offered as to the relative importance that scouts and coaches place on physical strength. It is however widely acknowledged that the priority of talent identification at this stage is more likely on technical ability. The existence of strength differences in the elite population in this thesis may suggest that the talent identification processes that currently exist do consider strength, or its game-specific manifestation to be important. While data on the genetic influence of strength provided here is insightful it is inherently limited by aspects of the experimental design implemented. For example, it is acknowledged that despite a relatively large cohort, the pooling of ethnicities to increase group size could reduce signs of genetic diversity between cohorts. Previous research has suggested there is considerable ethnic variations in typical frequencies of many genotypes (Williams & Folland 2008). It is unknown whether this would be the case for all genes though there is evidence suggesting it may be the case in those investigated here (*PPARA* (Maciejewska et al. 2011), *COLIA1* (Hu et al. 2011), *VDR* (Bahat et al. 2010; Bid et al. 2005) and *NOS3* (Rai et al. 2014)). It is proposed that the limitations around the genetics data would include that only four SNPs were investigated. It is known that considerably more genes play a role in athletic performance (Eynon et al. 2013) and future studies may look to increase SNP number investigated.

Figure 6.1. Schematic showing a general overview of the determinants of strength in soccer



The other key area of consideration in this thesis in the attempt to understand the importance of strength and soccer was the evaluation of the training stimulus. Training has been shown to be important in youth soccer players as it can lead to increased muscular strength (Keiner et al. 2014), which may correspondingly lead to improved soccer performance. The following section of this synthesis attempts to present some of the key practical/conceptual ideas listed drawn from Figure 6.1 that relate to potentially important practically considerations for strength development.

Training provision that has the potential to increase muscular strength, as part of an LTAD model seems insufficient in the club studied on the basis of the data in this thesis. This is likely due to limited exposure as time is prioritised towards soccer training. While recent Position Statements (Lloyd et al. 2016) seem to clearly outline potential strategies for the development of strength within soccer they do not acknowledge practical barriers that make close adherence to such policies difficult. It would therefore seem important that practical strategies to increase strength must attempt to minimise any disruption to other elements of the existing programming. The implementation of such a philosophy can be illustrated by attempts to increase the exposure to related work by utilising micro doses. For example, in the U9 to U11 age groups, as other age groups (e.g. U12 to U14s) there could be attempts to include small exposures to non-soccer training before or after soccer sessions. These interventions could also be done as additional exposures that can be safely done at home with minimal equipment. This provision would not only allow greater exposure to non-soccer training stimuli earlier than in the current model but facilitate the introduction of more complex exercises. It would be hoped that this may reduce some of the potential risks of early specialisation, highlighted in the review of literature. This may then ultimately aid the potential opportunities for increasing strength.

Practical recommendations around the data in this thesis must also be viewed within the context of the wider soccer population and to the broader aspects of training programming in youth soccer. Authors of a recent paper (Read et al. 2016) have been critical of the Elite Player Performance Plan, 2011 (EPPP; which makes recommendations around all elite academy training structures) for seeming to recommend early sport specialisation and an increased volume of on-pitch training hours per week in comparison to previous guidelines. The data in Chapter 3 shows that the time suggested by the EPPP (4 to 8 hr/wk. in 5 to 11 yr. olds, 12 to 16 hr/wk. in 12 to 16 yr. olds and up to 16 hr/wk. in 17 to 21 yr. olds) is considerably greater than the amount of exposure that is actually observed within this academy. The criticism of the EPPP training time recommendations being mostly soccer focused by Read et al. (2016), is a potential limitation as it could instead permit closer adherence to broader physically orientated training recommendations associated with relevant Position Statement adherence (written by some of the same authors). The interpretation of the data collected here is in general agreement of this view, as it is believed that, optimisation of strength training would require a shift in training philosophy to provide an opportunity to programme such training within an already busy schedule. This may require some educational interventions with coaches to enable them to understand the requirements to develop desirable player attributes that are not technically focussed. This may, over time, aid training restructuring to allow greater non-soccer training time. A difficulty around this though is that additional training time is likely only of use when the training prescription can be accurately determined. This would require the implementation of appropriate methodologies to evaluate both the acute and chronic training stresses associated with such work.

While the data gathered here in this thesis could be considered 'ecologically valid' and offer practical insights into elite populations (who are infrequently studied), they are not without limitation. When looking to quantify the variables around exercise in order to subsequently determine its success it is common to consider training type, frequency, duration and intensity. The design for evaluating training distribution did not allow the measurement of training intensity. The rationale behind this approach was that the practicalities of the data collection around the multiple training types required for the evaluation made it practically difficult to consistently measure intensity. It is accepted, on reflection, that consideration around training intensity and greater detail around training type may have allowed greater inferences to be drawn from the data presented here. An additional difficulty was the wider methodological problems in measuring the intensity of resistance training more generally. It is obvious that the ability to measure intensity would be useful in order to monitor more accurately player load throughout a training period, especially across training types. While the inclusion of such procedures is fundamental to the understanding of the exercise impulse they are also potentially beneficial in giving coaches confidence that additional strength training work could be safely integrated into a player's programme. One marker of intensity that could be used across training types in this instance is RPE load (RPE x session time). With specific consideration to markers of work done in resistance training, it has been previously noted that a standardised method has yet to be agreed upon (McBride et al. 2009). This has been attributed to the complex nature of variables encapsulating resistance exercise protocols. Proposed solutions currently include volume load (VL (repetitions [no.] multiplied by external load [kg]), maximum dynamic strength volume load (MDSVL (repetitions [no.] multiplied by [body minus shank mass (kg) plus external load (kg)]), time under tension (TUT), and total work (TW (force [N] multiplied by displacement [m]) (McBride et al. 2009). Despite conclusion that volume determination is necessary in resistance exercise, this suggests there is still much debate over the most appropriate method. Therefore, despite the acceptance that a marker, beyond duration would have allowed greater inferences about the results presented in this thesis, it is considered that it may propose a broader issue around the appropriateness of such a marker. The complexity of this issue may be intensified as this thesis investigated youth athletes, whom anecdotally undertake bodyweight exercises regularly. Such exercises have been acknowledged as particularly difficult to quantify, which should also be a future consideration (McBride et al. 2009).

If muscular strength is considered to be a desirable characteristic, consideration must be given to the methodology behind the method of evaluating strength performance. As with measuring intensity, determining appropriate measures of strength also pose a broader conceptual problem to researchers and practitioners in this area. As considered in Chapter 4, tests of muscular strength aim to offer, among other things, acute insight into the adaptations associated with a training programming for an individual (Young et al. 2014). Test selection is of significant importance when looking at test suitability. Practitioners must decide upon a test that is both valid and reliable and be practically suitable. The IMTP, as a test of muscular strength for elite youth soccer players has some limitations. As the test is isometric it may be difficult to draw practical parallels between its performance outcomes. In addition to measuring MVF in order to assess the successes of a strength training programme, other practical recommendations can be considered in order to achieve this goal. Greater familiarisation with the IMTP may allow reliable measurements of RFD in elite youth players. As well as allowing the measurement of further variables, such as RFD, a greater period of familiarisation may have also reduced any potential learning effect that may have been present within the MVF data in this thesis. This limitation was a result of the availability of both elite and control cohorts during testing. It is accepted that this may limit some of the certainty that can be carried with the conclusions of the specific experimental chapters in relation to MVF. Future studies may therefore look to conduct thorough familiarisation protocols to ensure learning effects have ceased. When accompanied with such rigour it seems that as powerful actions are important in soccer performance (Faude et al. 2012) the ability to record RFD as well as MVF would be advantageous. The use of ultrasound may also be considered to measure muscle pennation angle could be of benefit when assessing strength training. As ultrasound machines become cheaper and more portable, the feasibility of this increases. The addition of both measures would allow greater information than solely looking to MVF. Beyond test reliability/validity, and the use of new technology to provide muscle architecture data, test relevance may be a greater concern from a broader perspective. This thesis has considered the suitability of the IMTP among other commonly implemented tests for measuring muscular force, however its relevance to soccer performance could be questioned. As with most tests of muscular force production (some of which have been presented in the review of the literature), carryover into specific sporting performance is difficult to quantify. For example, in this instance the ability to maximally produce bilateral isometric force may not aid the tasks faced by an elite youth soccer player throughout a 90 minute soccer match. As a result, inferences around the findings of this project, and subsequent implications on youth soccer performance are very difficult to make. Future studies may look to investigate ecologically valid ways of assessing muscular force during soccer match play. In such a multi-factorial sport though, such tests may be difficult to devise.

Another issue that may influence test selection is biological maturity. Throughout this thesis the need to consider the biological age of a player has been highlighted. Methods for determining maturation status are just as important to consider as the selection of muscular force capability tests and are numerous in the literature. In this thesis maturity was separated according to proximity to PHV. This enabled us to attempt to determine whether maturation status played a role in MVF or the predominance of genotype or allele frequency. During the planning of this thesis the inclusion of other methodologies for determining maturation status were considered. These approaches were ruled out due to constraints around their practical implementation and cost. Despite considering the use of maturity offset to meet test criteria it is proposed that using skeletal age may be a more appropriate test for future research if possible. This may be especially beneficial when considering grouping based on maturity assessment in a broader theoretical and practical perspective. Increasingly, training programming, training groups and soccer matches are based on such maturation groupings, known in soccer terminology as “bio-banding”. The efficacy and effectiveness of assessing maturation is a fundamental theoretical and methodological challenge for the broader area of paediatric exercise physiology. As a result, it was desired to use the method most appropriate to the specific circumstances while still maintaining validity and minimising error. In addition to being critical of the method chosen to assess maturity, it is also of use to consider how force was reported during IMTP trials. In Chapter 4 a fixed scaling factor (MVF divided by body mass$^{0.66}$) was used as it was deemed appropriate for the sample being studied. The use of such a scaling factor allows for comparison of individuals of different sizes. Historically this factor has taken the form of ratio standard with body mass. In more recent years allometric scaling techniques have been used to examine the theory that muscle cross-sectional area and strength are a function of the second power of height (De Ste Croix 2007). It would likely be of benefit to consider suitable scaling factors derived from careful modelling of individual data sets, and therefore generate scaling factors that are sample specific rather than adopting assumed scaling indices (De Ste Croix 2007; De Ste Croix et al. 2009).

6.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Additional research would aid confirmation of the findings from this thesis. Specifically, further data would benefit the knowledge of programming of training, particularly strength training, employed by other soccer clubs. Knowledge of how typical the findings of this thesis are would determine suitability of its practical recommendations to other clubs. Similarly, repetition of the studies in Chapter 5 would suggest whether the trends seen in the examined club were typical. Specifically, it could be proposed how different training protocols might result in differing muscular strength development. Analysis of further SNPs with the potential to affect muscular strength may also aid understanding of the 'blueprint' of elite youth soccer players. Ultimately, future research should aim to aid practitioners in their programming in order to optimise player development and therefore increase soccer performance through increased physical performance and injury prevention.

Recommendation 1: How do training durations, intensities and distributions present in different elite youth soccer training academies and do they meet suggested guidelines for increases in muscular strength?

The findings from Chapter 3 demonstrate that despite elite soccer academies having input from experienced, qualified soccer and sports science coaches, programming fully utilising recommendations is not occurring. Despite the incremental introduction of training that may elicit increases in muscular strength, it is postulated it is not introduced early enough. Similarly, it is considered it is not implemented frequently enough to elicit continued adaptation. This may be due to insufficient coaches in younger age groups or a belief that it is less important than technical and tactical soccer training. The latter of these points could be debated within individual institutes though more research is required to investigate if this chapter's findings are consistent elsewhere. An addition to this study that may prove useful may be to interview soccer coaches to determine where they feel priorities lie in elite player development.

Recommendation 2: How do differing approaches to training programming across different clubs affect muscular strength?

The findings from Chapter 5 demonstrate the training data displayed in Chapter 3 were not sufficient stimuli to elicit continued adaptations in muscular strength. If prolonged adaptation were deemed desirable identification of successful programming would be advantageous. This could be achieved via a cross sectional study using alternative academies, identified using recommendation 1. Their employment of different training methodologies may offer a practical solution to the potential shortcomings identified in the academy in this thesis. This method would remove the potential practical difficulties that may be encountered should an attempt be made to introduce new programming strategies in clubs with established philosophies.

Recommendation 3: Do elite youth soccer players possess a greater total genotype score than a control population and does that score correspond to an association for greater MVF?

The findings from Chapter 6 demonstrate that no potentially favourable single genotype investigated was associated with muscular strength. Also, aside from *NOS3* rs2070744 no allele or genotype frequency differences were identified between cohorts. It is appreciated though that the interaction between genes is likely as important as a genes effect in insolation (Eynon et al. 2013). As a result, previously the analysis of multiple genotypes to offer a “total genotype score” (TGS) has been employed. This TGS is calculated using an algorithm (Williams & Folland 2008) to incorporate all favourable genotype scores for any given individual in a simple additive model. Total scores are mathematically transformed to lie within the range 0–100 and labelled the TGS. A TGS of 100 represents a “perfect” polygenic profile for a soccer player and a TGS of 0 represents the “worst” possible profile for a soccer player. This has been used previously in different populations (Ruiz et al. 2010) including soccer players (Egorova et al. 2014). It is suggested that if the data presented in Chapter 6 were extended to include other SNPs with potential associations for strength as well as other soccer academies knowledge would be enhanced.

6.4 CONCLUSION

There are relatively few studies examining training, muscular strength or genetic profiles associated with muscular strength of elite youth soccer players. The findings in this thesis demonstrate that, within the cohort studied, training undertaken does not allow sufficient specific training to continually increase MVF. It can also be concluded that those examined do not have favourable genotypes of genes with potential influence over MVF to be predisposed to strength or trainability for strength. Additional research is required to increase the power of this study as well as adding variables to take into account intensity as well as duration of exercise. This information could eventually lead to improvements in strength and conditioning planning in order to increase adaptation to strength training throughout stages of development. It is hoped ultimately this would translate to improved soccer performances.

CHAPTER 7

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CHAPTER 8

APPENDICIES

CONSENT FORM

Participants younger than 18 yrs. and parent/guardians

Sports science profiling of elite youth soccer players and non-elite counterparts

To be completed by participant and parent/guardian

1. I confirm that I have read and understand the information provided for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and that this will not affect my legal rights.
3. I understand that any personal information collected during the study will be anonymised and remain confidential
4. I agree consent for the performance of the physical tests and collection and storage of saliva samples to allow the genetics investigation to be carried out.
5. I give consent to allow the investigation of unlimited gene polymorphisms from the tissue sample.
6. I agree to take part in the above study

Name of Participant	**Date**	**Signature**

Name of Parent	**Date**	**Signature**

Name of Researcher	**Date**	**Signature**
TOM BROWNLEE	25/03/15	

CARER INFORMATION SHEET

Title of Project:
Sports science profiling of elite youth soccer players and non-elite counterparts.

Name of Researchers and School/Faculty:
Andrew O'Boyle, Head of Fitness Elite Development, Liverpool Football Club Academy.
Tom Brownlee, PhD Researcher, School of Sport and Exercise Science, Liverpool John Moores University

Liverpool Football Club Academy have been invited to take part in a research study. Before you decide if you wish to give your son the option of participating in this research project, it is important that you understand why the research is being done and what it involves. Please take time to read the following information. Ask us if there is anything that is not clear or if you would like more information.

What is the purpose of the study?
The aim of the current study is to assess the physical capacities (strength, speed, agility, power, endurance) of the LFC elite youth soccer players compared with a non-elite control group and to evaluate the effects of genetic make-up on physical performance levels.

Does the individual have to take part?
No. It is up to you and the individual to decide whether or not to take part. If you both agree you will be asked to sign the consent form attached. The individual is still free to withdraw at any time and without giving a reason. A decision to withdraw will not affect their rights/any future treatment/service they receive.

What will happen to the individual if they do take part?
To participate in this project the individual must be healthy and have no illness or pre-existing injuries. This study will be conducted in the training ground of Liverpool Football Club Academy (The Academy, The Liverpool Way, Kirkby, Knowsley, Merseyside, L33 7ED). If the individual volunteers to participate in this project, they will be asked to perform the procedures detailed below.

When the individual arrives at Liverpool Football Club Academy they will be have their body mass (kg) and height (cm) measured. The individual will then be asked to provide a saliva sample by filling a small tube with saliva. We will extract DNA from the cells in this sample. The individual will then be asked to perform physical performance tests for speed (30m sprint), strength (isometric mid-thigh pull) and power (vertical and horizontal countermovement jump test).

Are there any risks / benefits involved?
As with any explosive exercise, there is a risk of a muscle injury. Therefore, to ensure this risk is minimised, all participants will be required to perform a 10 min of warm up activity during all sessions.

Will my taking part in the study be kept confidential?
Data collection

- Data collection remains strictly confidential between the participant and the researcher.
- Personal information will be treated in the strictest confidence with no association been made between the subjects identities and the data observed.
- All data collected from the participant will be anonymised and identifiable by a code – the participant cannot be identified by simply reading the code.

Data storage

- All information/data will be stored confidentially and only accessed by members of the research team. At the end of the study, all personal identifiable information will be deleted.
- Information linking the participant to the participant code will be stored in a secure place, only accessible by the researcher.
- The handling and storage of all samples, e.g. buccal and saliva samples, and extracted DNA, will comply with the Human Tissue Act legislation. The genetic material will be stored so that it can be re-analysed for different gene polymorphisms at a later date.

Contact Details of Researcher
Further information may be obtained from the following:

Head of Fitness & Elite Development, Liverpool Football Club. Andy O'Boyle. Email: Andy.OBoyle@liverpoolfc.com

PhD Researcher, LFC Sports Science Department: Conall Murtagh. Email: tom.brownlee@liverpoolfc.com

Project Supervisors: Prof. Barry Drust. Email: B.Drust@ljmu.ac.uk

Tom Brownlee,
PhD Research
Student,
LJMU University,
Tom Reilly Building
Byrom Street,
Liverpool,
L3 3AF.

Dear Sir/Madam,

Your son is invited to take part in a research project conducted in collaboration between Liverpool John Moores University (LJMU) and Liverpool Football Club (LFC) Academy. The project will investigate potential differences in maximal power, strength and speed between elite youth LFC football players and age-matched non-elite children/adolescents/young adults. The project will also investigate potential associations between power/strength/speed and genetic make-up in both elite and non-elite individuals, as it is not known how important genetic make-up is in determining elite football-specific performance.

Before you decide whether you give your consent for your son to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the attached study information sheet. Ensure that you read this information carefully and discuss it with others if you wish. If you require any more information please do not hesitate to ask.

Thank you for reading this.

Kind Regards

Tom Brownlee
PhD Candidate
Liverpool John Moores University
Email:

CONSENT FORM

Participants younger than 18 yrs. and parent/guardians

Sports science profiling of elite youth soccer players and non-elite counterparts

To be completed by participant and parent/guardian

1. I confirm that I have read and understand the information provided for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and that this will not affect my legal rights.
3. I understand that any personal information collected during the study will be anonymised and remain confidential
4. I agree consent for the performance of the physical tests and collection and storage of saliva samples to allow the genetics investigation to be carried out.
5. I give consent to allow the investigation of unlimited gene variants from the tissue sample.
6. I agree to take part in the above study

Name of Participant **Date** **Signature**

Name of Parent **Date** **Signature**

Name of Researcher **Date** **Signature**

CARER INFORMATION SHEET

Title of Project:
Sports science profiling of elite youth soccer players and non-elite counterparts.

Name of Researchers and School/Faculty:
Tom Brownlee & Conall Murtagh, PhD Researchers, School of Sport and Exercise Science, Liverpool John Moores University (LJMU)
Andrew O'Boyle, Head of Fitness Elite Development, Liverpool Football Club Academy.
Dr Rob Erskine, Senior Lecturer, School of Sport and Exercise Science, LJMU
Professor Barry Drust, School of Sport and Exercise Science, LJMU

Your son is being invited to take part in a research project conducted in collaboration between LJMU and Liverpool Football Club Academy. Before you decide if you wish to give your son the option of participating in this research project, it is important that you understand why the research is being done and what it involves. Please take time to read the following information. Please ask us if there is anything that is not clear or if you would like more information.

What is the purpose of the study?
The aim of the current study is to assess the physical capacities (strength, speed, agility, power, endurance) of the LFC elite youth soccer players compared with a non-elite control group of similar age, and to investigate the potential influence of genetic make-up on physical performance levels.

Does the individual have to take part?
No. It is up to you and the individual to decide whether or not to take part. If you both agree you will be asked to sign the attached consent form. The individual is still free to withdraw at any time and without giving a reason. A decision to withdraw will not affect their rights/any future treatment/service they receive.

What will happen to the individual if they do take part?
To participate in this project the individual must be healthy and have no illness or pre-existing injuries. This study will be conducted in the training ground of Liverpool Football Club Academy (The Academy, The Liverpool Way, Kirkby, Knowsley, Merseyside, L33 7ED). If the individual volunteers do participate in this project, they will be asked to perform the procedures detailed below.

When the individual arrives at Liverpool Football Club Academy they will be have their body mass (kg) and height (cm) measured. The individual will then be asked to provide a saliva sample by filling a small 2 mL tube with saliva. We will later extract DNA from the cells in this sample. The individual will then be asked to perform physical performance tests for speed (30m sprint), strength (isometric mid-thigh pull) and power (vertical and horizontal countermovement jump test).

Are there any risks / benefits involved?
As with any explosive exercise, there is a risk of a muscle injury. Therefore, to ensure this risk is minimised, all participants will be required to perform a 10 min of warm up activity during all sessions, supervised by the researchers.

Will my taking part in the study be kept confidential?

Data collection

- Data collection remains strictly confidential between the participant and the researcher.
- Personal information will be treated in the strictest confidence with no association between the subjects identities and the data obtained.
- All data collected from the participant will be anonymised and identifiable only by a code – the participant cannot be identified by simply reading the code.

Data storage

- All information/data will be stored confidentially and securely and only accessed by members of the research team. At the end of the study, all personal identifiable information will be deleted.
- Information linking the participant to the participant code will be stored in a secure place, only accessible by the researcher.
- The handling and storage of all saliva samples and extracted DNA will take place at Liverpool John Moores University, and will comply with the strict regulations according to the **Human Tissue Act legislation**. The genetic material will not be shared with any person outside of the LJMU research team and will be stored so that it can be re-analysed for different gene variations at a later date. This is considered good research practice by the Human Tissue Authority, as it enables us to make better use of the samples we collect, rather than having to ask more people to provide DNA.

Contact Details of Researcher
Further information may be obtained from the following:

PhD Researchers, LFC Sports Science Department: Tom Brownlee & Conall Murtagh. Email: tom.brownlee@liverpoolfc.com

LJMU Project Supervisors: Prof. Barry Drust. Email: B.Drust@ljmu.ac.uk; Dr Robert Erskine. Email: R.M.Erskine@ljmu.ac.uk

Head of Fitness & Elite Development, Liverpool Football Club. Andy O'Boyle. Email: Andy.OBoyle@liverpoolfc.com