## THE UNIVERSITY OF HULL

Isokinetic muscular strength and performance in youth football: relationships with age, seasonal variation and injury.

being a Thesis submitted for the Degree of Doctor of Philosophy

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by

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"Little by little, one travels far" J.R.R. Tolkein (1892 - 1973)

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#### Abstract

The primary aim of the current project was to investigate the isokinetic muscular strength and performance of elite male youth footballers, and the relationships with age, seasonal variation and injury. A secondary aim was to use the information gathered to target muscle strain injury prevention strategies to particular age groups and times, and evaluate the effect.

The primary aim was achieved by establishing normative patterns for muscular strength and performance of elite male youth footballers (grouped according to chronological and biological age) across a competitive season of youth football in Chapters Four and Five. Isokinetic muscular strength (characterised by peak torque (PT) and peak torque relative to body weight (PTBW)) of the hamstrings (H) and quadriceps (Q) using both concentric (CQ, CH) and eccentric muscle actions (EH) was evaluated. Muscular performance of the same muscle groups (characterised by H:Q ratios (conventional (CHQ) functional (FHQ)), asymmetry (dominant (dom):non dominant (ndom) leg ratios (e.g. CQ:CQ)), and angle of peak torque (AoPT)) was also investigated which necessitated an isokinetic speed of 60 °/s. Isokinetic evaluation was completed three times over the course of a regular playing season (start of season (SS) mid season (MS) and end of season (ES)).

Participants were grouped according to chronological age (n=152, under 12 (U12) - under 18 (U18)) and biological maturation (according to Pubertal Development Scale (PDS 1 - 5) n=134). Forty seven participants completed SS, MS and ES isokinetic evaluation. Bilateral isokinetic evaluation consisted of five maximal repetitions of CQ and CH, followed by five repetitions of EH, leg dominance was counter-balanced. Repetitions two-four were used to calculate PT, PTBW, dom:ndom and AoPT for CQ, CH and EH, CHQ and FHQ; these measures were compared across chronological age groups using a mixed model ANOVA. Dom:ndom CQ, CH and EH were compared across chronological and biological age groups using a mixed model and evaluation. Additionally, the relationship between chronological and biological age, and PT/PTBW was investigated using a mixed model ANOVA within PDS group three. For analysis of seasonal variation a mixed model ANOVA was applied for all isokinetic measurements which considered time (SS, MS, ES), leg dominance (dom, ndom) and age group (U12 -U15) with a further mixed model ANOVA performed on CQ:CQ, CH:CH and EH:EH. Where appropriate SIDAK corrections were applied and the level of significance was accepted at  $p \leq 0.05$ .

The main findings were that youth footballers did not increase their PT and PTBW EH in-line with CQ and CH as chronological and biological ageing progressed, this lead to a significant FHQ imbalance at U18. Dom:ndom CH comparisons identified that the chronologically younger and biologically less developed groups displayed a significantly stronger dom leg which may be explained through the concepts of skill acquisition and trainability. Biological age was not found to exert any additional effect over and above that of chronological ageing as significant differences in muscle strength still existed according to chronological age group within PDS group three. Additionally, AoPT EH and PT EH were found to be significantly negatively correlated on both legs which supported a potential mechanism for non contact hamstring muscle strain injury during running. Analysis of seasonal variation revealed that all PTBW measures showed a MS decrease. This may be related to breaks in normal training activity and links appropriately to times of peak injury incidence highlighted in youth football.

In order to achieve the secondary aim of the current project Chapters Four, Five and Six investigated the relationship between isokinetic muscular strength and performance, muscle strain injury of the thigh, and injury risk attenuation.

A retrospective and prospective injury audit was undertaken for the elite male youth football participants. For the retrospective approach participants were grouped according to chronological age (n=147) or biological age (n=128) and indicated using a self-report injury form their history (ever, (Hx)) or recent history (12 months, (Hx12)) of hamstring, quadriceps and adductor injuries. Approximately each player had an Hx of muscle strain injury and 0.56-0.59 of players had an Hx12. The hamstrings were the most commonly injured muscle group and the prevalence of muscle strain injury Hx and Hx12 increased with chronological and biological age. The prospective audit (n=50) identified that 0.16 of players sustained a muscle strain injury during the season, 0.08 of these being to the hamstrings.

Between group comparisons (one way ANOVA with SIDAK correction) were also performed to investigate the difference in isokinetic measures between those participants who had an Hx12 of muscle strain injury and those who did not. It was discovered that for Hx12 of an injury to the dom hamstrings the injured group had less PTBW CH and EH on the dom leg. The injured group also had more inner range AoPT CH. These findings linked appropriately to the reported mechanisms and risk factors for hamstring injury but the exact direction of cause and effect could not be established. To this end a logistic regression analysis was undertaken in an attempt to predict which group (injured vs. non injured the 50 participants would belong to, using evidenced based risk factors in the experimental model. No predictive relationship between risk factors (including altered isokinetic muscular strength and performance) could be established. The information regarding the relationship between injury and muscular strength and performance may highlight a role for isokinetic screening to ensure adequate rehabilitation from injury.

Injury risk attenuation strategies were investigated through an exercise intervention using the U18 age group following a break from football activity. The participants were split based on their FHQ at initial isokinetic evaluation (via odd and even placing) to form control (n=8) and intervention groups (n=8). Isokinetic evaluation was conducted as previously outlined and the exercise intervention targeted the hamstrings. Only six of the control group and seven of the intervention group completed the study and were compared using a mixed model ANOVA. Results showed that the intervention group were not significantly different to the control group post intervention for any of the isokinetic muscular strength and performance measures, though both groups significantly improved over time for the ndom leg CHQ and PTBW EH, and FHQ improved for both legs. Contamination of the control group may explain the lack of significant difference between groups. However, the exercise intervention was not targeted to individuals who displayed prior alterations to isokinetic muscular strength and performance, and this approach was discussed using the results of one member of the intervention group.

In summary, the current project achieved the stated aims by discovering normative patterns of isokinetic muscular strength and performance according to age and seasonal variation. Injury risk attenuation strategies were targeted appropriately to the U18 age group following a break from football activity. However, the applied evidence based exercise may have been more effective if targeted to 'risk' after isokinetic screening.

#### List of published works and works in press

Forbes, H., Bullers, A., Lovell, A., McNaughton, L.R., Polman, R.C. & Siegler, J.C. (2009). Relative Torque profiles of elite male youth footballers: Effects of age and pubertal development. *International Journal of Sports Medicine*, 30 (8) 592-597.

Forbes, H., Sutcliffe, S., Lovell, A., McNaughton, L.R. & Siegler, J.C. (2009). Isokinetic thigh muscle ratios in youth football: Effect of age and dominance. *International Journal of Sports Medicine*, 30 (8) 602-606.

Forbes, H. & Siegler, J. (2012). Seasonal variation in the isokinetic strength of youth soccer players: Effects of age and dominance. *Gazzetta Medica Italiana*, 171 (3) 253-61.

Forbes, H., Siegler, J. & Lohkamp, M. The effects of an eight week hamstring strengthening programme on the muscular performance of youth footballers. Poster presented at United Kingdom Sport and Exercise Medicine (UKSEM) Conference, 26-30<sup>th</sup> November, 2011, ExCel Arena, London.

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## List of Abbreviations, Acronyms and Symbols

%	Percent
x	Mean
<	Less than
±	Plus or Minus
≤	Less than or equal to
0	Degrees
°/s	Degrees per second
ACL	Anterior Cruciate Ligament
ACSM	American College of Sports Medicine
ANOVA	Analysis of Variance
AoPT	Angle of Peak Torque
ATFL	Anterior Talo-Fibular Ligament
BW	Body weight
CoE	Football Centre of excellence
СН	Concentric hamstrings
CH:CH	Dominant to non-dominant concentric hamstrings ratio
CHQ	Concentric hamstrings to concentric quadriceps ratio
cm	Centimetres
CQ	Concentric quadriceps
CQ:CQ	Dominant to non-dominant concentric quadriceps ratio
CRB	Criminal Records Bureau
dom	Dominant
dom:ndom	Dominant leg to non dominant leg ratio
EH	Eccentric hamstrings
EH:EH	Dominant to non-dominant eccentric hamstrings
EMG	Electromyography
EQ	Eccentric quadriceps
EQ:EQ	Dominant to non-dominant eccentric quadriceps
ES	End of season (April)
FA	The Football Association
FFM	Fat free mass
FHQ	Eccentric hamstrings to concentric quadriceps ratio
FIFA	Fédération Internationale de Football Association

F-MARC	Medical research centre of FIFA
GSR	Graduate Sport Rehabilitator
Н	Hamstrings
H:Q	Hamstrings to quadriceps ratio
Hx	Injury history
Hx12	Injury within the last 12 months
kg	Kilograms
LTADM	Long-Term Athlete Development Model
m	Metres
Μ	Modifiable
MCL	Medial Collateral Ligament
MS	Mid-season (January)
n	Number of subjects in a sample
NCAA	National Collegiate Athletic Association
ndom	Non-dominant
Nm	Newton meters
NM	Non-modifiable
р	Probability statistic
PCL	Posterior Cruciate Ligament
PDS	Pubertal Development Scale
PDS 1	Pre-pubertal
PDS 2	Beginning pubertal
PDS 3	Mid pubertal
PDS 4	Advanced pubertal
PDS 5	Post pubertal
рр	Page number
РТ	Peak torque
PTBW	Peak torque divided by body weight
Q	Quadriceps
r	Pearson's correlation co-efficient
RI	Reportable Injury
ROM	Range of Motion
S	Seconds
SD	Standard deviation
SDM	Soccer Development Model

SPSS	Statistical Package for the Social Sciences
SS	Start of season (September)
TLI	Time lost to injury
U9	8-9 year olds
U10	9-10 year olds
U11	10-11 year olds
U12	11-12 year olds
U13	12-13 year olds
U14	13-14 year olds
U15	14-15 year olds
U16	15-16 years olds
U17	16-17 year olds
U18	17-18 year olds
U21	Under 21 years of age
USA	United States of America
VO <sub>2 max</sub>	Maximal Oxygen Uptake
VS.	Versus
W	Watts
wk	Week

#### **Chapter One: General introduction**

#### 1.1. Introduction

In England 1.75million boys participate in football activity over 10 times each week, of these approximately 10,000 are registered with formal football training facilities (Malina, 2005). These elite youth footballers are therefore subject to the documented stresses and strains of football from an early age. However, to date very little literature has investigated how this population 'grows into' and become physically influenced by their sport, or alternatively the particular physical characteristics displayed by those who 'make the grade' in comparison to their peers.

Football is an intermittent sport which requires periods of: walking, jogging, running, sprinting, various kicking techniques and ball control, cutting movements, turning, jumping, landing and a degree of contact between the players (Brophy et al., 2007; Kellis and Katis, 2007; Wong and Hong, 2005; Reilly, 1996). Formal youth football training may begin at eight years of age where the characteristics and requirements of the adult game are gradually taught and developed. Initially, coaching focus is reserved for individual basic skills. Skill and performance in smaller sided teams is subsequently introduced with shortened periods of game play, until finally full sided and full match lengths at approximately 14 years of age (Stratton et al., 2004). Throughout this developmental period youth footballers also undertake physical preparation and train fitness characteristics prized in the adult game with the aim of performance enhancement. An important aspect is muscular strength and power of the lower limb (Stratton et al., 2004, Wein, 2001) therefore sport specific patterns of muscular strength and performance, muscle balance and asymmetry may be expected.

Playing football as an adult or youth therefore carries an inherent risk of injury. Injuries sustained in the youth training period must be measured by the consequences for future potential skill and career acquisition, in addition to the normal considerations of time loss and medical care costs (Price et al., 2004). A recent study by the Football Association (FA) which included all of the of the football academies in England (Price et al., 2004) heavily influenced the current project because the authors outlined the injury problems faced by front line medical staff as part of their day to day clinical work load. Price et al. (2004) reported that up to six percent of total football development time was lost due to injury, and that the most common injuries were ligament sprains to the ankle and strains of the thigh muscles. This may serve as a challenge to those interested in the prevention of injury.

The current project aimed to increase understanding of aetiology and risk of injury in youth football. In order to achieve this, it was first important to discover the muscular strength and performance characteristics of elite youth footballers and how they might differ from other

sporting populations and non sport-specific youths. Investigation of this type may serve to highlight areas of increased injury risk through comparison to the physical demands of youth football and proven injury risk factors. Identification of particular risks would be of benefit to coaches, clinicians and trainers who work with youth footballers as injury prevention strategies may then be appropriately designed and implemented. It was also important to understand what injury prevention strategies would be justified and effective for youth footballers. Therefore, a progressive aim of the current project was to explore the efficacy of prevention strategies for this population. Throughout the current project the concept of evidenced-based professional practice permeated the narrative, the discussion, and the recommendations made by the author. It was considered of crucial importance that the findings outlined could be usefully acted upon by 'front line' coaches, clinicians and trainers.

#### 1.2. Definition of terms and concepts within the current project

Youth was defined as the period of time between childhood and adulthood (Webster's Reference Library, 2005) and childhood the period from the end of the first year of post natal life until adolescence (Malina, Bouchard and Bar-Or, 2004; Beunen and Thomis, 2000). Adolescence is a period of rapid cellular growth, maturation and pubertal development and (accounting for individual variance) occurs between the ages of 10 and 22 in males (Malina, Bouchard and Bar-Or, 2004). In practice, adolescence may be quantified in terms of overt pubertal maturity which begins with neuroendocrine changes which stimulate physical change, and finally adult reproductive function (Malina, Bouchard and Bar-Or, 2004). Growth refers to increases in size of the whole or parts of the individual, and is distinct from maturation which relates to the progressive achievement of adult status through pubertal development (Baxter-Jones, 2008; Beunen and Thomis, 2000), though both must be viewed as transformative processes (Malina, Bouchard and Bar-Or, 2004). These distinctions are important because young footballers are all youths, however not all of them have reached puberty and progressed into adolescence. None of the participants in the current project had reached adulthood, the period after which final stature and maturation has been reached (Beunen and Thomis, 2000).

For clarity, it was also important to define chronological and biological ageing, and growth and development throughout youth as the relationships may be complex. By way of explanation, Baxter-Jones (2008) cited that all children mature to become adults through biological ageing, though a tall adolescent may still be delayed in biological maturation in comparison to their peers. Furthermore, the dimensions of the adult as a result of their growth differ exponentially even when their chronological age is similar (Baxter-Jones, 2008).

[2]

To illustrate these concepts one must acknowledge the presence of a temporal continuum. All the aforementioned parameters such as growth, development, maturation, and ageing (chronological and biological) may exist along this continuum, and any measurements taken of individuals throughout their lifespan may be represented as events on that continuum. In this context chronological age can be quantified in minutes, hours, days, months and years with the initial point a birth date and time (Malina, Bouchard, and Bar-Or, 2004). In sport, for competition and training purposes participants of similar chronological age are often grouped according to this measure of ageing (for example, under 12 years of age). Biological age, which includes the processes of growth and pubertal maturation, cannot be quantified in the same way because it relates to the beginning and end of the body's natural advancement (Malina, Bouchard, and Bar-Or, 2004). Biological age is commonly quantified by the measurement of specific processes (for example, sexual maturation throughout puberty or growth stimulated increases of height/weight) and can be self reported (often to protect modesty) or directly objectively evaluated using comparative normative scales. Figure 1.1 shows a temporal continuum with the periods of interest, youth and adolescence, highlighted as well as the mean chronological onset of the major events of growth, maturation and puberty (via biological ageing) included. However, regular physical activity is one of many factors which may influence growth and maturation (Baxter-Jones, 2008) meaning that the continuum (Figure 1.1) should only be considered as a guide.



Figure 1.1. Temporal continuum showing the mean chronological age for the events of biological ageing for males

In the current project, 'muscular strength' was evaluated at specific points across the continuum. Muscular strength is defined as the production of force (De Ste Croix, 2008); it is an important component of task performance in children and adolescents (Malina, Bouchard and Bar-Or, 2004) and is therefore frequently monitored by researchers (De Ste Croix, Deighan and Armstrong, 2003). In children and adolescents limited studies have tracked this variable with specific reference to biological and chronological ageing, despite strength evaluation forming an essential component of physical fitness testing/training and rehabilitation from injury (De Ste Croix, 2008). Strength is different to torque which is measured in Newton metres (Nm) and is representative of muscular force applied around an axis of rotation as a moment, for example, a joint (Richards, 2008; De Ste Croix, Deighan and Armstrong, 2003). However, many authors use the measurement of isokinetic torque as an indirect dynamic measure of muscle strength through movement (Chan and Maffulli, 1996). Isokinetic evaluation controls the speed of the muscular contraction, equalising acceleration and deceleration of the limb to ensure constant velocity (Richards, 2008, De Ste Croix, Deighan and Armstrong, 2003; Chan and Maffulli, 1996). Thus, although isokinetic actions are not necessarily representative of the actions of daily living, isokinetic evaluation achieves a high degree of reliability and allows maximum torque to be applied throughout range of motion which is not possible with other strength measurement devices (De Ste Croix, Deighan and Armstrong, 2003; Chan and Maffulli, 1996). Isokinetic dynamometry is also safe to use in all populations due to the minimal effort required to control the load (De Ste Croix, Deighan and Armstrong, 2003).

The term muscular performance has been previously used to collectively describe muscular strength, power and endurance (Suei et al., 1998). However, for the current project muscular performance was used to describe the manner of functioning of the muscle. This included information regarding the position of the peak force exerted within the range of motion (AoPT), and also consideration of muscle (to muscle) balance and asymmetry (leg to leg). For clarity, and to contextualise these muscular performance parameters, they were specifically defined as they became relevant in later chapters. With regard to this, the anatomical detail of the hamstrings and quadriceps muscle groups were also of primary interest for the current project. The hamstrings and quadriceps play a role in the dynamic stabilisation of the knee joint through anatomical support of the anterior and posterior cruciate ligaments (ACL/PCL) (Ahmad et al., 2006; Stone and Stone, 2000). The hamstrings are situated on the posterior thigh and are made up of the: biceps femoris, semitendonosis and semimembranosis muscles. The quadriceps are comprised of the: vastii group (intermedialis, lateralis, medialis) and the rectus femoris. Table 1.1 outlines the teno-osseus attachments of the hamstrings and quadriceps muscle groups, while Figure 1.2 illustrates both muscle groups along with their surrounding structures.

[4]

Muscle Group	Muscle	Proximal bony attachment/s	Distal bony attachment/s	Action	
	Biceps Femoris	Long head—ischial tuberosity of the pelvis and sacrotuberous ligament	Lateral side of the head of the fibula and the lateral condyle of the tiba	Flexes leg at the knee. Long head also assists in extension of the thigh at the hip	
		Short head—linea aspera and lateral supracondylar ridge of the femur, lateral intermuscular septum.			
Hamstrings	Semi- tendonosis	Ischial tuberosity	Medial surface of the shaft of the tibia	Flexes leg at the knee. Assists in medial rotation of the knee in flexion, also assists in extension of the thigh at the hip	
	Semi- membranosis	lschial tuberosity	Postero-medial condyle of the tibia	Flexes leg at the knee joint. Assists in medial rotation of the knee in flexion, also assists in extension of the thigh at the hip	
	Rectus Femoris	Anterior head—anterior inferior iliac spine of the pelvis	Superior patella, then via patella ligament to the tuberosity of the anterior tibia	Extends leg at the knee, flexes thigh at the hip	
		Posterior/reflected head—ilium above the acetabulum of the pevis			
Quadriceps	Vastus Lateralis	Intertrochanteric line, inferior border of the greater trochanter, gluteal tuberosity and the lateral lip of the linea aspera of the femur	Lateral margin of the patella, then via patella ligament to the tuberosity of the anterior tibia	Extends leg at the knee	
	Vastus Intermedialis	Linea aspera, lateral supracondylar line and anterior and lateral surfaces of the upper two thirds of the femur, lateral intermuscular septum	Forms deep aspect of quadriceps tendon to superior patella, then via patella ligament to the tuberosity of the anterior tibia	Extends leg at the knee	
	Vastus Medialis	Intertrochanteric line, medial supracondylar line, and medial lip of the linea aspera of the femur, medial intermuscular septum.	Medial border of the patella, then via patella ligament to the tuberosity of the anterior tibia	Extends leg at the knee	

## Table 1.1. Bony attachments of the hamstrings and quadriceps muscle groups

(Stone and Stone, 2000)



(Gray, 2005, pp 277 and 285)

Figure 1.2. Labelled illustration of the hamstrings (a) and quadriceps (b) muscle groups (including surrounding musculature)

The hamstrings and quadriceps may be considered an antagonistic pair because of the anatomical ability to bring about opposing movements across the hip and knee joint. This was important to understand because the term muscle balance was used throughout the current project to describe the agonist/antagonist function of these muscle groups. The recommended ratio for healthy function of hamstrings:quadriceps torque (H:Q) has been accepted as  $\geq$  0.60 (Coombs and Garbutt, 2002). A leg to leg analysis, i.e. dominant (dom) to non dominant (ndom) comparison of muscle to muscle balance was termed asymmetry. For clarity, this meant that the variables of interest through isokinetic evaluation for the current project were: muscular strength (peak torque (PT) of the hamstrings and quadriceps), and muscular performance which incorporated the angle of PT though knee joint range (AoPT), muscle balance (H:Q ratios) and muscular asymmetry (dom:ndom ratios).

A final concept, which was important to describe for the current project, related to the system of formal football education in England. This is not generally controlled by the FA, but directly by clubs and other training centres. This formal education begins at age eight when youngsters may be invited to either an academy or a centre of excellence, which is almost always directly associated with a club (Stratton et al., 2004). At academies/centres of excellence youth footballers are provided with coaching, training and medical support and it was this multidisciplinary team for whom the current project aimed to provide useful information and recommendations.

Academies and centres of excellence organise the training and competition of youth footballers into chronological age categories prefixed by 'under', for example under 12 (U12). This convention was followed throughout the current project in an attempt to ensure maximum validity and comparability. Additional definitions were that: football game play was defined as matches between opposing teams from different clubs and football training was team based and individual physical activity under the control or guidance of staff, with the aim of maintaining or improving skill, condition or performance (Fuller et al., 2006). The term 'trainability' was also used to describe the propensity of individuals or groups to respond physically to training (Matos and Winsley, 2007; Malina, Bouchard, and Bar-Or, 2004).

#### **Chapter Two: Review of literature**

#### 2.1. Introduction

The aim of this review of literature was to critically analyse 1) 'normal' isokinetic strength and muscular performance development in males throughout late childhood and adolescence, 2) the presence and nature of a possible effect of training for youth football on isokinetic strength and muscular performance, and 3) the relationship of muscular strength and performance with injury.

Initially papers and text books concerning the assessment and interpretation of 'normal' isokinetic thigh musculature strength development throughout childhood and adolescence were considered. This allowed an appreciation of the isokinetic hamstrings and quadriceps strength and muscular performance as a result of growth, maturation, and chronological and biological ageing, without reference to sport specific demands and possible adaptations therein. This exercise formed an important comparator to the elite male youth footballers who were the participants for the current project. The literature in this section was partially gathered from books written by leading authors in the field who have aggregated previous works into more accessible formats. The rest of the literature reviewed specifically focused upon isokinetic thigh musculature strength measurements before, during, and after maturational pubertal changes or 'growth spurts', and longitudinal/cross sectional studies performed across chronological age groups. All studies used normal non sport-specific school age populations, and used varying protocols to measure biological ageing and isokinetic strength and muscular performance. A final important aim for this first section of the review was to acknowledge that the scope of the current project did not allow for a direct measure of the underlying cellular processes of growth, maturation and ageing, rather the functional outcomes of these such as bodily hair growth, physique alteration, vocal changes and isokinetic muscular performance development.

The second section of the literature review concerned the effects of football activity and exercise on the aforementioned normative isokinetic muscle strength and performance of the hamstrings and quadriceps throughout chronological and biological ageing. The purpose was to, firstly, identify whether youth footballers developed particular hamstrings and quadriceps muscle strength and performance characteristics, and secondly, to quantify differences to 'normal' non sport-specific male adolescents with the aim of highlighting any possible relationship to injury. To achieve a level of perspective for the rest of the current project the demands of youth football were also reviewed in this section. It was considered important to understand: the nature of the game (physiological, biomechanical and technical demands), coaching aims, logistical considerations, talent identification, and progression.

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The third section of the literature review considered injury in youth football and the possible relationships with chronological and biological ageing, and muscular strength and performance. This allowed the scope of the current project to extend to injury risk, incidence and prevention in youth football. In order to investigate this topic the initial concern was to evaluate the extent of the 'injury problem' in youth football by following the first stage of van Mechelan, Hlobil and Kemper's (1992) sequence of prevention. The aim of this was to highlight temporal periods of increased injury incidence throughout chronological and/or biological ageing, and youth football training. The next stage was to investigate the causational factors for the injuries reported as common in youth football which may be related to the complex changes inherent to chronological and biological ageing. As previously discussed, the chronological age group system used in England may contain individuals who are at differing stages of muscular strength development, growth and maturation. Identification of particular injuries with particular causes for this population led to a need to review the successes and failings of previously attempted injury prevention strategies and ultimately defined the goals and expectations of the current project.

The final task which was undertaken as part of the review of literature was to summarise the major findings of interest, and to highlight areas of missing information and knowledge. The purpose was to reveal areas of disagreement or missing data amongst previous authors, and to highlight the role of the current project in answering those research questions. In addition, the specific strengths and weaknesses of the literature in the field were assimilated and informed the methodology of the current project. There was a clinical focus to this task in which the needs of those working with the population of interest were considered. This was to ensure that the results and findings of the present study would be clinically useful and have practical application in 'the field'. The task concluded by stating the derivation of specific research aims, objectives and hypotheses which were addressed specifically in each of the experimental chapters.

#### 2.2. Muscular strength and performance in children and adolescent males

Skeletal muscle provides a propulsive force via contraction which is required for all physical activity and this force may be measured as muscular strength (Malina, Bouchard, and Bar-Or, 2004). Skeletal muscle, as all tissue, is capable of growth and maturation throughout ageing. The processes which underpin this have been discussed by previous authors (Malina, Bouchard, and Bar-Or, 2004; De Ste Croix, Deighan and Armstrong, 2003; Beunen and Thomis, 2000; Ozmun, Mikesky and Surburg, 1994) and were relevant to the current project because the same processes may also underpin responses and adaptations to the demands placed upon the neuro-musculoskeletal system as a result of training for youth football.

Skeletal muscle tissue is differentiated by the first month of post natal life, and completes complex adaptive processes which are probably echoed throughout human life (Malina, Bouchard, and Bar-Or, 2004; Beunen and Thomis, 2000). The first process, myogenesis, describes a process of cell proliferation resulting in new muscle fibre formation (termed hyperplasia), usually as a response to stress/challenge but also as a result of injury (Malina, Bouchard, and Bar-Or, 2004). Myogenesis is not however, considered a prime reason for the observed increases in muscle mass noted during growth in adolescence (Malina, Bouchard, and Bar-Or, 2004; Beunen and Thomis, 2000). The second process, hypertrophy, describes an increase in muscle cell and fibre diameter and length. Hypertrophy may occur during biological ageing and is considered a major determinant of muscular strength in adolescents and adults; a process which is also mediated by stress and loading of the muscular tissue (Malina, Bouchard, and Bar-Or, 2004). Hypertrophy may therefore be related to training and playing youth football and could theoretically result in patterns of muscular performance development which are sport specific. However, hypertrophy is not considered to be a major reason for observed strength increases prior to puberty (i.e. in childhood) with research suggesting that hormonal interactions during pubertal maturation are important for this process (Matos and Windsley, 2007). A final consideration for the process of growth and maturation of skeletal muscle concerns the neuromuscular motor unit. The changes to this unit throughout maturation, which may be architectural or performance related, are still poorly understood (Matos and Windsley, 2007; Malina, Bouchard, and Bar-Or, 2004; De Ste Croix, Deighan and Armstrong, 2003) though authors have postulated that many strength adaptations in a pre-pubertal population are derived from this mechanism (Matos and Windsley, 2007). These conclusions were largely based on deductive reasoning by eliminating myogenesis and hypertrophy but also due to an observed increase in electromyographic activity of the muscles post resistance training in a pre-pubertal population (Ozmun, Mikesky and Surburg, 1994).

In summary, it appears that a number of mechanisms for increasing strength and muscular performance may be actively utilised in a youth population, and it appears that the pre and post pubertal groups may react differently to training. Unfortunately, there were few certainties regarding the complex cellular physiology of growth and maturation of skeletal muscle tissue because this has not been thoroughly investigated throughout adolescence. A possible reason for this dearth of research is that invasive techniques are needed to analyse skeletal muscle cell changes, and this may have ethical and developmental considerations in young participants (De Ste Croix, Deighan and Armstrong, 2003). Thus, the majority of researchers in this field have therefore considered the external outcomes of growth and maturation of muscle in terms of

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changes to muscle action (strength), function and performance, both physiologically and biomechanically.

#### 2.2.1 Action of skeletal muscle: measuring strength and muscular performance

Skeletal muscle tissue acts via three types of contraction: concentric which describes muscle shortening, eccentric which describes muscle lengthening, and isometric which describes no motion (Richards, 2008; Bar-Or and Rowland, 2004). These actions constitute contraction specific muscular strength, and therefore measurement of these actions over time can illustrate temporal patterns of muscle strength development as a result of ageing, and/or growth and maturation. However, in order for accurate comparisons to be made between participants and the literature there are factors that must first be controlled. For example, it is accepted that as adolescent males grow and mature they become taller and heavier (Stang and Story, 2005; Beunen and Thomis, 2000). Increased height and weight may be attributable to changes in body composition and an increase in the length of the 'long' bones of the skeleton as a result of hormonal interaction (Malina, Bouchard, and Bar-Or, 2004), this may result in adaptation of muscle, and an increase in the number of sarcomeres in series (i.e. length) and in parallel and therefore may have an effect on strength (De Ste Croix, 2008). Therefore, measurements of strength and muscular performance in the adolescent male population need to be relative to the stature of the individual in question.

An appropriate method for this is to apply a ratio adjustment to strength measurements (De Ste Croix, Deighan and Armstrong, 2003), the most common of which is to divide the peak strength measurement by body weight (BW). This may allow for more accurate comparisons across age, maturational status and population. There have been criticisms of the use of BW to normalise peak strength measures because BW does not constitute wholly contractile tissues capable of force production and transmission (De Ste Croix, Deighan and Armstrong, 2003). However, Housh et al. (1989) showed that fat free mass was significantly and highly correlated with BW (r= 0.96) which supports the use of BW. Other factors such as a ratio adjustment of strength to muscle cross sectional area, limb length and FFM estimation were discussed by Welsman and Armstrong (2008) and De Ste Croix, Deighan and Armstrong (2003), but require further investigation due to inconsistencies and problems with estimation equations.

Muscular strength may be evaluated using a variety of methods and much of the early data regarding muscular strength of children and adolescents presented in Malina, Bouchard and Bar-Or (2004) utilised functional parameters such as 'arm hangs', maximal grip strength and 'sit up' exercises. These are isometric holding exercises, all of which have later received criticism because children may have a decreased ability to activate the entirety of their motor capability under

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intense conditions (Backman and Henriksson, 1988) and it is not possible to apply ratio adjustments for BW to this type of data (De Ste Croix, 2008). In contrast, isokinetic evaluation allows for an accurate assessment of muscular function under a high level of experimental control due to the constant velocity of the joint movement (De Ste Croix, Deighan and Armstrong, 2003; Baltzopoulos and Kellis, 1998; Chan and Maffulli, 1996). Isokinetic dynamometry is also safe to use in youth populations as only minimal effort is required to control the load (De Ste Croix, Deighan and Armstrong, 2003). Furthermore, isokinetic evaluation can act as a sophisticated and sensitive comparator over time (Baltzopoulos and Kellis, 1998) when compared to, for example, the levels (one to five) of the oxford scale for manual muscle strength testing (Richards, 2008). Studies that have focused on childhood and adolescent populations to date have tended to evaluate the thigh musculature, and have considered PT measured at different angular velocities. Many studies have used slower isokinetic speeds such as 30°/s and 60°/s with their youth populations, as results are considered to be more reliable and more likely to elicit a maximal voluntary effort (De Ste Croix, Deighan and Armstrong, 2003; Baltzopoulos and Kellis, 1998).

Another advantage of isokinetic evaluation is the range of muscular performance factors which can be considered in addition to maximal voluntary PT (Richards, 2008). A variable of interest for a growing population may be AoPT, as this may link to the length tension relationship of the growing musculature which is considered a determinant of strength performance (Sergeant, 1998). This could also be affected by the growth of the long bones expected in adolescence giving an altered lever arm (Malina, Bouchard, and Bar-Or, 2004; De Ste Croix, 2007). AoPT has been linked to altered muscular performance after injury (Brockett, Morgan and Proske, 2004) and essentially describes the point of PT within the range of motion of a joint. This muscular performance variable could therefore link to football skills such as kicking which require a particular technique and fairly prescriptive repetitive muscle actions.

A further variable of interest may be muscle balance in terms of H:Q ratio which may be conventional (CHQ) or functional (FHQ) (Coombs and Garbutt, 2002). CHQ is calculated by dividing peak concentric hamstring muscle action by peak concentric quadriceps muscle action, a muscle action which does not arise during anatomical function (Coombs and Garbutt, 2002). FHQ is calculated by dividing peak eccentric hamstring muscle action by peak concentric quadriceps action and attempts to mimic the eccentric action of the antagonist to decelerate the concentric action of the agonist (Coombs and Garbutt, 2002). This variable is also often linked to injury because actions such as kicking and sprinting in football require concentric action of the quadriceps which must be controlled by action of the hamstrings to avoid injury.

Another variable is a bilateral, or leg to leg ratio which may illustrate asymmetry (Fousekis, Tsepis, Vagenas, 2010; Richards, 2008; Baltzopoulos and Kellis, 1998). This was of interest because youth footballers have been reported to have a dom leg which is preferred for kicking actions, meaning that the ndom leg acts as a stabiliser (Rahnama, Lees and Bambaecichi, 2005). Muscular imbalance or asymmetry of any type is referred to as an injury risk factor (Baltzopoulos and Kellis, 1998) and may also link to the finding of Blimkie (1989) that in youth, muscles may develop strength and performance differently in response to physical demand, tissue loading and hormonal interactions.

Isokinetic evaluation appears to be a reliable method to gain information regarding PT and muscular performance. In contrast to some clinical and functional methods, isokinetic evaluation can give detailed information regarding muscular performance factors such as AoPT, muscle balance (H:Q) and asymmetry (dom:ndom). Therefore, the next task for the current review was to investigate isokinetic strength and muscular performance in 'normal' non sport-specific adolescent males. Using this distinct population it was possible to gain important comparative information which may allow for the identification of specific strength and muscular performance patterns in youth footballers.

## 2.2.2. The relationship between age (chronological and biological) and isokinetic hamstrings and quadriceps muscular strength and performance

Table 2.1 summarises the findings of the various authors who have investigated normal development of isokinetic strength in non sport-specific adolescent male populations. The papers included were of cross-sectional or longitudinal design and participants were mostly grouped and compared according to chronological age group. Some authors (Seger and Thorstensson, 2000) also investigated the effects of maturation by grouping according to biological age. Where possible concentric and eccentric strength measurements for the thigh musculature have been extrapolated using PT ratio adjusted to BW (PTBW), however not all authors used this method to control for body stature (annotated Table 2.1). Many authors did not report muscular performance factors and remained focused on PT.

Table 2.1 also confirmed that isokinetic hamstring and quadriceps PT increases with chronological ageing in adolescent males. Application of the PTBW ratio suggested that this increase occurred even when changes in BW were controlled. This finding was in agreement with Maffulli, King and Helms (1994) who compared 453 athletes aged between nine and 18 from four sports, Wiggin et al. (2006) who reported isokinetic PT for the hamstrings and quadriceps of children of aged six to 13 (n=3587), and Beunen and Thomis (2000).

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These studies were not included in Table 2.1. Maffulli, King and Helms (1994) used an isometric strength measure and this may have inherent problems for a youth population since children may experience discomfort during rapid development of force inhibiting maximal output (De Ste Croix, 2008). Wiggin et al. (2006) presented percentile rather than mean data and Beunen and Thomis (2000) reviewed existing data.

All of the reviewed evidence above suggested that it was possible to accept that chronological ageing results in an increase in hamstrings and quadriceps PT. This increase may also be independent of the changes in BW regulated by adolescent hormones of growth and maturation (Housh et al., 1995). This was of interest because it suggests that factors of muscular strength determination which would not affect BW, such as force production via increased neuromuscular activity, may indeed be active throughout chronological ageing.

Author (date)	Design	Participants	Isokinetic parameters	Main findings
Holm and Vollestad (2008)*	Cross sectional	High school males aged 7-12 years (n=	PT of H and Q concentrically,	Knee extension and flexion PT increased with age (7-12)
		184)	H:Q, @ 60°/s and 240°/s,	at both speeds. No effect of age on H:Q ratio in males.
			dom leg only	
Barber-Westin, Noyes and	Cross sectional	Non specific sporting active males aged	PTBW of H and Q	No effect found for dominance (leg to leg ratio),
Galloway (2006)		9-17 years (n= 177)	concentrically @ 300°/s ,	significant increases in knee extension and flexion PT
			bilateral study	from 9-14 years though no further increase noted, HQ
				ratio highest for youngest age group, decrease noted to
				age 14 then plateau. No effect of age on H:Q.
Kanehisa, Abe and Fukunaga	Three year	High school males; aged 12.7 - 13.4	PT of Q concentrically	At 60°/s and 180°/s effect of one year ageing significant
(2003)#	longitudinal study	years (n= 10) at study start	@60°/s, 180°/s and 300°/s,	(increase) , only at 60°/s were all three years of ageing
			right leg only	significant (increase)
De Ste Croix et al. (2002)	Four year	High school males aged 10.0 (± 0.2)	PT of Q and H concentrically	No influence of age or maturity on the development of H
	longitudinal study	years (n= 20) at study start	@ 30°/s, 60°/s, 90°/s, 120°/s,	and Q isokinetic length strength at any speed when
			180°/s	stature and mass accounted for.
Seger and Thorstensson	Five year	High school males aged 11.6 (± 0.1)	PT of Q concentrically and	PT of knee extension significantly increased throughout
(2000)	longitudinal study	years (n= 9)	eccentrically @ 45°/s, 90°/s	course of the study at all speeds. PTBW increased
			and 180°/s	eccentrically but not concentrically. No age effect on
				Eccentric: concentric ratio of Q. Post pubertal Q PT
				significantly increased

Table 2.1. Reported findings of studies of isokinetic strength and muscular performance in 'normal' non sport-specific adolescent males

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De Ste Croix, Armstrong and	Cross sectional	High school/higher education student	PT of Q and H concentrically	PT of knee extension and flexion increased with older
Welsman (1999)		males; grouped 8-9 years (n= 23), 13-14	@30°/s, 60°/s, 90°/s, 120°/s,	age group regardless of speed.
		years (n= 23), 18-27 (n=24)	180°/s, dom leg only	
Holmes and Alderink (1984)	Cross sectional	High school males aged 15 - 17years	PT of Q and H concentrically	No effect of age on PTBW, no difference for leg to leg
		(n=17)	@ 60°/s and 180°/s, dom:	comparison, no effect of age on endurance.
			ndom leg comparison.	
			Endurance of Q and H	
			concentrically	
Miyashita and Kanehisa	Cross sectional	School age males 13 - 17 years (n= 275)	PT of concentric Q @ 210°/s,	Linear increase in PT Q as age increases except between
(1979)*			unilateral study	16 and 17 years.
			*data not pre	sented /BW. #data presented PT/muscle cross sectional area

Seger and Thorstensson (2000; Table 2.1) suggested significant increases in isokinetic quadriceps PT as a result of biological ageing and this was in agreement with Maffulli, King and Helms (1994). The observed increases may be related to increased serum levels of anabolic hormones in pubertal males which precede muscle strength gains during adolescence (Ramos et al., 1998; Hansen et al., 1999). Indeed, Malina, Bouchard and Bar-Or (2004) agreed that early maturing boys show a distinct advantage over average maturing and late maturing boys in activities such as jumping and sprinting which rely upon strength, power and speed. Neither Segar and Thorstensson (2000) nor Maffulli, King and Helms (1994) were able to demonstrate that PT increases were solely attributable to biological ageing when individuals of similar chronological age were compared, this was confirmed by De Ste Croix et al. (2002). In contrast, Fragoso et al. (2005) stated that biological ageing through sexual maturation via self reported Tanner staging was an independent factor for the explanation of maximal strength of a leg press in their 70 young male football participants (aged 13-16 years). This controversy may be partly due to the increased importance of chronological age when biological ageing is equal, in that the chronologically older participant may be expected to have increased learning time resulting in greater motor ability (Fragoso et al., 2005). Overall, the isolated maturational influences on isokinetic muscular strength and muscular performance remain to be extrapolated. With reference to this uncertainty, Baldari et al. (2009) recommended that practitioners evaluate both biological and chronological age, having established this by correlating both types of age, salivary androgen hormones and fat free mass with increased long jump performance in 51 young males.

The complex interaction between chronological and biological age, and muscular strength and performance was important for the current project. It was clear that both chronological and biological age were methodological considerations, however while chronological ageing is simple to quantify (days, months and years from birth) assessment of biological ageing may be achieved using a number of methods. The gold standard (Johnson, Doherty and Freemont, 2009) is to measure skeletal age via x-ray examination. One problem with this approach is that different methods for x-ray examination yield varying conclusions making cross comparison difficult (Malina et al., 2007). A second issue is that the cost of this procedure may be prohibitive and exposes the individual to radiation. As an alternative, non invasive measures of biological age have gained researchers interest. One popular measure is to assess the advancement of physical secondary sex characteristics which develop through the course of pubertal maturation. The most common method for this is the sexual maturation scale, developed by Tanner (1962) which was designed as criteria to evaluate the individual through direct examination by a medical practitioner. This approach may be considered unpleasant by children, adolescents and their parents, and thus various self-reporting measures have gained popularity within the literature

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(Petersen et al., 1988). Self-reporting requires an individual to liken the development of their secondary sex characteristics according to a set standard of relevant physical characteristics using a scale. This method allows researchers to consider the presence and development of secondary sex characteristics with little embarrassment for the participant. Though concerns have been raised regarding validity, literature suggests that some questionnaires can be considered both reliable and valid (Petersen et al., 1988).

A further function of Table 2.1 was to highlight the varied methods which have been used to quantify the effect of ageing and maturation on isokinetic muscular strength in non sport-specific young and adolescent males. Of the methods used it is often considered that the longitudinal design is the most 'sought after' (De Ste Croix et al., 2002). However, most of the research presented used a cross sectional design which allowed for a larger number of participants and thus increased the external validity of the results. Of the studies presented above, only three (Holm and Vollestad, 2008; Barber-Westin, Noyes and Galloway, 2006; Miyashita and Kanehisa, 1979) used a 'large' sample (100 participants). Conversely, Kanehisa, Abe and Fukunaga (2003), De Ste Croix et al. (2002) and Seger and Thorstensson (2000) used a combined sample of 39 participants who were evaluated over three to five years. The high subject numbers of these studies may be considered an advantage because genetic and environmental factors can be controlled (Segar and Thorstensson, 2000). For the purposes of the current project, this suggested that these six studies were the most useful for comparison to a youth football specific population later in the review of literature, but also that time and subject availability could be a factor in designing experimental chapters.

A final consideration to be made when comparing literature in this field was that many of the studies used different isokinetic speeds (Table 2.1). This was important because concentric PT is likely to decrease as speed of testing increases due to the force-velocity relationship (De Ste Croix, 2007). Conversely, a functional muscle strength ratio (like FHQ) will increase in accordance with angular velocity (De Ste Croix, 2007), while a conventional ratio (like CHQ) may remain unaffected because both components of the ratio would decrease, depending upon where in the range of motion that the ratio is taken. This distinction is methodologically relevant because it suggests that accurate comparisons of muscle strength and performance require similar angular velocity to ensure meaningful analysis. In youths low speeds of isokinetic evaluation (under 130°/s) have been recommended due to the decreased amount of motor pattern learning that is required to co-ordinate a fast contraction (De Ste Croix, Deighan and Armstrong, 2003). Therefore, as a result of the literature reviewed 60°/s was deemed appropriate for cross-comparison of the literature. This met with the recommendations of De Ste Croix, Deighan and Armstrong (2003) but also allowed for the greatest amount of overlap with the existing literature.

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Both chronological and biological ageing contributed to muscular strength increases in adolescent males, though the extent of the independent influences of these factors was disputed. It was concluded that the current project should consider both of these factors in future analysis using a self reporting measure of biological age. In addition, the aforementioned review of literature identified six studies which were very useful for comparison to the youth football population of interest, and has also isolated a particular isokinetic speed which will allow for a meaningful comparison between populations and with the existing literature. These conclusions also allowed for a comparative assessment of the data presented in the aforementioned six studies of interest, giving the present author the expected specific normative values for 'normal' non sport-specific males of different chronological age groups.

# 2.2.3. Comparative normative data for isokinetic strength and muscular performance of the hamstrings and quadriceps in 'normal' non sport-specific adolescent males

Figure 2.1 (pp 20) illustrates the average PTBW at 60°/s from the dom leg quadriceps and hamstrings measured concentrically (CQ, CH) and the CHQ as reported by age in the following papers (which were included in Table 2.1) Holm and Vollestad (2008), Kanehisa, Abe and Fukunaga (2003), De Ste Croix et al. (2002), De Ste Croix, Armstrong and Welsman (1999), Holmes and Alderink (1984), and Miyashita and Kanehisa (1979). Where studies did not present their data normalised to BW a calculation was performed dividing average PT by the average BW for the age group in question to give a ratio. Unfortunately, no data was available for CH at 60°/s for ages 14 - 18 years, CQ at 18 years and H:Q for ages 14-15 years from the papers included in the present review. In addition, only data relating to the dom leg could be included due to authors performing a unilateral evaluation.

Figure 2.1 also suggests that CQ and CH PTBW increase with chronological ageing in a fairly linear manner. CQ displayed lower values than the line of best fit at ages 7, 8, 16 and 17 though the trend was for a steady increase. The reasons for the lower values could not be elucidated from critical analysis of all of the contributing authors work and may represent an area of future interest. Unfortunately, the line of best fit for CH may be slightly misleading and steep because of missing data for the older ages. From Figure 2.1 it also appears that the greatest PTBW may be produced by the quadriceps which is in line with Wiggin et al. (2006) and Gilliam et al. (1979). This is probably related to the presence of the patella as a sesamoid bone within the quadriceps (Figure 1.2b pp 6) favourably altering the angle of pull and larger cross sectional area of this muscle compared to the hamstrings (Figure 1.2a pp 6) which also lack the biomechanical torque production ideal of a single insertion point (Richards, 2008; Norris, 2000). Thus, this pattern of greater torque for CQ was also expected to appear in the youth football population discussed later in the review.
H:Q muscle balance appears to remain relatively stable (Figure 2.1) which is probably because the increases in CQ and CH were reported as relatively equal across the time frame. The CHQ for all age groups was 0.5 - 0.6 which approximately meets with the recommendation for healthy function of Coombs and Garbutt (2002).



(Literature data included: Holm and Vollestad, 2008; Kanehisa, Abe and Fukunaga, 2003; De Ste Croix et al., 2002; De Ste Croix, Armstrong and Welsman, 1999; Holmes and Alderink, 1984; Miyashita and Kanehisa, 1979)



## 2.2.4 Summary

This review of 'normal' non sport-specific adolescent male muscular strength and performance throughout late childhood and adolescence confirmed that isokinetic PT increased as a result of both chronological and biological ageing, even accounting for the effect of increased BW. The quadriceps were stronger than the hamstrings and there were fairly equal strength increases across chronological ageing which meant that CHQ did not show any considerable change, remaining stable at 0.5 - 0.6. Unfortunately, an isolated effect for chronological or biological ageing could not be elucidated, with many authors using deductive reasoning to postulate that the physiological basis for strength increases may be related to neuro-musculoskeletal adaptations as yet unexplained. This review also illustrated that the previous literature in the field was largely limited to concentric muscle actions, particularly of the quadriceps, and the majority only considered a unilateral analysis which limits the information available regarding leg to leg asymmetry. This suggests that investigations which consider eccentric muscle action, and focus on bilateral actions of the hamstrings and quadriceps may be novel and add to knowledge in the field.

#### 2.3. Muscular strength, performance and the training structure of elite male youth footballers

The aim of this second section of the review of literature was to critically compare the isokinetic muscular strength and performance of the hamstrings and quadriceps of youth footballers as compared to the aforementioned age-matched 'normal' non sport-specific male population. The first consideration was to review literature which investigated the possibility for sport specificity of isokinetic strength and muscular performance across sports, and the mechanisms through which particular patterns of strength and muscular performance may materialise. This process allowed the author to highlight whether the sport of football might be expected to present exclusive muscular strength and performance patterns. The second consideration was to review the normative isokinetic data regarding the muscular strength and performance of the hamstrings and quadriceps data gathered in the first section of the review of literature and present that concurrently with the limited data available for youth footballers. This process aimed to quantify the expected muscular strength and performance patterns for youth footballers and quantify any possible differences. A progressive aim was to then consider if these differences matched with the demands of the sport of football at youth level, and if there was clinical implications for injury risk and prevention of injury.

## 2.3.1. Sport specificity of isokinetic strength and muscular performance

It has been noted that an increased understanding of the complex role of a young individual's musculoskeletal system, training theory and effects, and the mechanical demands of sport would benefit professionals working with athletic children (Maffulli, 1990). Exercise adaptations have been extensively researched in adults, however the adaptations to training which may be expected from a youth population may not be the same because the processes of chronological and biological ageing complicates 'trainability' (Matos and Winsley, 2007).

Research to date, agrees that participation in youth physical activity, or training for youth sport can bring about increases in muscular strength when compared to a non-active population. Authors also caution that elite young athletes may actually be part of a 'self-selected' gifted group who choose to perform physical activity/training due to an innate talent or skill, therefore generalisations should be avoided (Malina, 1989; Bailey and Mirwald, 1988). Data regarding the isokinetic strength of male youth participants of: basketball (aged 11 - 17 years; Buchanan and Vardaxis, 2003; Gerodimos et al., 2003), wrestling (age range 8 - 18 years; Camic et al., 2010; Housh et al., 1996; Housh et al., 1995; Housh et al., 1989), speed skating (age range 10 - 18 years; Nemoto, Kanehisa, Miyashita, 1990), and gymnastics (age range 12-27 years; Russell et al., 1995) was present in the literature. Synthesis of the findings suggested that isokinetic concentric PTBW of the hamstrings and quadriceps significantly increased with age as was expected. However,

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across the sports, the observed increases were not always similar with regard to magnitude and linearity. A notable finding was that of Housh et al. (1989) who were the only authors to report decreasing hamstring PTBW across chronological ageing at both 30°/s and 180°/s in high school wrestlers (n = 195, groups: ≤15 years, 15.01 - 16.00 years, and 16.01 - 17.00 years) though this was not apparent by age 17. This finding resulted in Housh et al. (1989) citing no significant increase in PTBW for the hamstrings as a result of chronological ageing, which was in contrast to the normative data presented earlier in the review and may suggest sport specific muscular strength and performance. Alternatively, since Housh et al. (1989) used high school athletes, it may be possible that the intensity of training was not high enough to elicit an effect on muscular strength, or that that the performers who were enrolled in high school did not represent an elite population. A contrasting finding was that speed skaters showed significantly higher quadriceps PT than age matched controls at 16 years of age (Nemoto et al., 1990).

The data gathered from youth basketball players was perhaps the most extensive. Buchanan and Vardaxis (2003) and Gerodimos et al. (2003) used an isokinetic speed of 60°/s and reported reciprocal H:Q ratios and dom:ndom asymmetry which was rare. The PT values reported by Buchanan and Vardaxis (2003) were systematically lower by approximately 36% than those presented by Gerodimos et al. (2003), despite Buchanan and Vardaxis (2003) employing combined age groups of either 11- 13 or 15 - 17 years and Gerodimos et al. (2003) using yearly age groups. Buchanan and Vardaxis (2003) presented low H:Q ratios (0.47 at 11-13 years and 0.43 at 15-17 years), compared to Holm and Vollestad (2008) (0.58 at age 12 and 0.68 at age 11) and for Gerodimos et al. (2003) (0.62-0.69 at age 12 years). In contrast, the ndom:dom ratio from Buchanan and Vardaxis (2003) or Gerodimos et al. (2003) included this type of analysis. It should be noted that Buchanan and Vardaxis (2003) conducted isokinetic evaluation after tournament based game play and, despite leaving and a one hour rest period, there may have been a fatigue effect upon their data.

There was limited data to suggest sport specific isokinetic muscular strength and performance across chronological ageing, though several interesting trends were highlighted. To the present author's knowledge no data existed which considered biological ageing. This meant that the current project builds on previous literature by assessing these missing elements through collecting football specific data. As stated previously, the main problems for comparative analysis noted for this section were the use of different isokinetic speeds and the protocols used by authors in the field.

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A further point of note was that little/no data appeared to exist which considered the eccentric performance of the muscles in the aforementioned sports, which may be viewed as a weakness due to the anatomical workings of the reciprocal muscle groups (Fields et al., 2005; Coombs and Garbutt, 2002). There was also a paucity of data which considered muscular performance in terms of H:Q balance, asymmetry, and especially AoPT. Thus, it was not possible to address the question of whether isokinetic strength sport specificity might exist in these parameters.

## 2.3.2. Normative isokinetic muscular strength and performance data for youth footballers

There have been few investigations concerning isokinetic hamstring and quadriceps muscular strength and performance in youth footballers. Of particular note was a longitudinal investigation taking account of biological ageing by Holm, Steen and Olstad (2005) spanning 11 years, and a large population cross sectional analysis by Kellis et al. (2001) who considered chronological ageing. Other authors have tended to present information which is specific to chronological age groups (Iga et al., 2006; Amato et al., 2003; Chin et al., 1994) or which has compared chronological age groups (Rochcongar et al., 1988; Leatt, Shephard and Plyley, 1987) and even football training history (Iga et al., 2009). There have also been studies which have considered high school footballers as a specific population, and these studies have been largely based in the United States of America (USA). It was decided to omit the results of high-school analysis from the normative data for two reasons. Firstly, due to the possibility that the intensity of high school training may have proved too low to elicit a sport specific effect (as in the Housh et al. (1989) study). Secondly, to maintain the relevance and comparability to the club based English system.

Many studies have specifically investigated club and elite youth footballers. There was agreement that youth footballers display a different pattern of strength, power, and muscular performance to untrained individuals (Maffulli, King and Helms, 1994; Capranica et al., 1992). Unfortunately, to the present author's knowledge, no studies have compared isokinetic muscular strength and performance over chronological and/or biological ageing between youth football and other sports. Thus, a key aim for the present review of literature was to compare the isokinetic muscular strength and performance of non sport-specific males to youth footballers of similar chronological age. This was achieved in Figures 2.2 and 2.3 and utilised the noted literature from the first section of this review of literature (pp 18) and the two largest studies of youth footballers (Holm, Steen and Olstad, 2005; Kellis et al., 2001).

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(Literature data included for Non Football: Holm and Vollestad, 2008; Kanehisa, Abe and Fukunaga, 2003; De Ste Croix et al., 2002; De Ste Croix, Armstrong and Welsman, 1999; Miyashita and Kanehisa, 1979. Literature data included for youth football population: Holm, Steen and Olstad, 2005; Kellis et al., 2001)

#### Figure 2.2. CQ in youth footballers vs. 'normal' non sport-specific youths

Figure 2.2 (above) shows that youth footballers increase their CQ PTBW as a result of chronological ageing, though there appeared to be a particular pattern. CQ PTBW appeared to rise more sharply and be higher for youth footballers as compared to the non sport-specific population, apart from at the younger age groups. This links appropriately to the nature of football as a sport predominated by kicking activities (Lees and Nolan, 2002; Howe, 1996) which may have the effect of strengthening the quadriceps muscles. The difference was particularly evident when the older age groups were compared which may also be explained by the nature of training for football as a youth. At approximately 16 years of age youth footballers tend to sign 'full-time' contracts for their clubs, therefore it could be expected that the volume of physical training for the sport might also increase. Alternatively, as a result of being contracted professionals it could also be argued that the youth players who are still training/playing football beyond the age of 16 would be the most elite and therefore possibly the most genetically gifted to meet the demands of their chosen sport. These factors may be expected to result in increased CQ PTBW.

Figure 2.3 illustrates that youth footballers increase their CH PTBW across chronological ageing. Youth footballers CH PTBW appeared to rise less sharply in comparison to non sport-specific males after age 13. This may be due to the missing data for the non sport-specific population resulting in an abnormally steep line of best fit. Nonetheless, if the lines of best fit at the youngest age groups were accepted, there is also a suggestion that youth footballers have greater CH PTBW initially, which then fails to increase in line with the 'normal' population, the opposite of the

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observed trend for CQ. A possible explanation could, again, be that football is a kicking and therefore concentric quadriceps dominated sport (Howe, 1996). However, more data is required to confirm the existence of this effect due to the aforementioned ambiguous line of best fit. Elucidation of this effect may be of interest to coaches and clinicians for both performance and injury prevention.



(Literature data included for Non Football: Holm and Vollestad, 2008; Kanehisa, Abe and Fukunaga, 2003; De Ste Croix et al., 2002; De Ste Croix, Armstrong and Welsman, 1999; Miyashita and Kanehisa, 1979. Literature included for youth football population: Holm, Steen and Olstad, 2005; Kellis et al., 2001)



A different pattern of muscular strength throughout chronological ageing may link to the nature of the football academy or centre of excellence training which young footballers undertake from eight years of age with the aim of becoming professional adult footballers (Stratton et al., 2004). Age eight (U9) was therefore the age at which the CQ and CH data strands began for youth footballers in the Holm, Steen and Olstad (2005) and Kellis et al. (2001) studies. However, at the opposing end of the data strand, when youth footballers may cross into the ranks of professional adult players, there was no significant difference between the muscular strength of the quadriceps and hamstrings of the professional players, under 21s (U21) and under 17s (U17) when evaluated at 60°/s and normalised to BW (Lehance et al., 2009). Thus, a final finding from Figures 2.2 and 2.3 may be that by approximately 17 years of age youth footballers are close to reaching their maximal adult strength output and pattern (Lehance et al., 2009). This may be of importance because it suggests that muscular strength patterns identified in youth could continue through to adulthood, meaning that any inherent injury risk factor may also do the same.

Regarding muscular performance, it was difficult to compare muscle balance (H:Q ratios), asymmetry (leg to leg ratios) and AoPT across ageing since little comparative data was available for the 'normal' non sport-specific children and adolescents considered earlier. However, Iga et al. (2009) reported that in their sample of three groups of age matched (15 ± 1years) conventionally trained footballers, general lower limb resistance trained footballers and controls (n= 15 per group) there were indications that football training did alter muscle balance. The FHQ for the conventionally trained footballers was significantly lower than the control group and resistance trained group. In contrast, the resistance trained footballers showed more equal FHQ than the conventionally trained footballers. This suggested that general lower limb resistance training may be useful in mediating the trend for imbalance in conventionally trained footballers, possibly because the hamstrings were targeted in addition to the quadriceps in the Iga et al. (2009) study. Another finding regarding muscle balance was a trend for CHQ to be most imbalanced in older youth age groups (under 18 (U18)) (Rochcongar et al., 1988; Leatt, Shephard and Plyley, 1987). This may be because the quadriceps gained greater strength than the hamstrings between the ages of 16 and 17 (Rochcongar et al., 1988).

Iga et al. (2009) did not report any notable effect for dom:ndom asymmetry for their participants, which was in agreement with Rochcongar et al. (1988) who compared three different age groups of youth footballers (16, under 16 and 14) but were not included in Table 2.2 due to their use of different isokinetic speeds (30°/s and 180°/s). Also in agreement was Lehance et al. (2009) and Capranica et al. (1992) who observed no bilateral asymmetries in any of their groups including professional adult and youth players. In contrast, Kellis et al. (2001) reported that across all the age groups included in their study (10-17 years) the dom leg (chosen to kick with) was significantly 3-10% stronger than the ndom. These differences may be explained by the smaller subject numbers of Lehance et al. (2009) n=57, Iga et al. (2009) n=45 and Capranica et al. (1992) n=20 which may not have yielded sufficient power to highlight dom:ndom asymmetry. Rochcongar et al. (1988) and Kellis et al. (2001) had 166 and 158 participants respectively, thus it is possible that modern youth football training practices may be responsible for the emergence of this effect. However, further research would be required to substantiate this assertion.

For adult footballers, there was literature suggesting that professional playing age, as opposed to chronological age lead to muscular strength and performance adaptations (Fousekis, Tsepis and Vagenas, 2010; Voutselas et al., 2007). There was an inverse relationship between years of play and asymmetry (i.e. as years of play increased asymmetry decreased). Also, a marked increase in isokinetic strength of the hamstrings and quadriceps from short (5-7 years), to intermediate (8-10 years) of professional playing age. This was in opposition to the assertion of Malina et al. (1989) that any population differences would probably be caused by the 'normal' ageing and

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development of genetically advantaged individuals independent of their sport. Unfortunately, an effect for training and playing football on muscular strength and performance has not yet been made apparent for a youth population.

With respect to the above, Table 2.2 (pp 29) was used to clarify and highlight the entirety of the current information regarding isokinetic muscular performance variables (H:Q ratios, asymmetry, and AoPT) of the hamstrings and quadriceps of youth footballers throughout the youth football training period, and into the professional game. The information presented here exclusively used the speed of 60°/s for comparative purposes. CHQ in youth footballers was not affected by chronological ageing and this trait was common for the dom and ndom leg (Kellis et al., 2001; Table 2.2). This was in agreement with Holm, Steen and Olstad (2005) who performed a longitudinal analysis of the isokinetic muscle performance in growing boys from pre-teen to maturity (12 -17 years), though these authors performed their evaluations at five designated biological age markers rather than chronological age markers. Therefore it may be concluded that CHQ could be expected to remain a stable trait throughout youth football academy training regardless of chronological or biological ageing. Only Kellis et al. (2001) reported information regarding muscle balance (CHQ and FHQ). FHQ showed a similar pattern to CHQ for their sample, although a slight trend for higher FHQ was highlighted at the youngest age group (Table 2.2). Due to the nature of the FHQ as a ratio variable it could be postulated that this was due to either lower CQ PT or higher EH PT. However, when dom:ndom eccentric quadriceps (EQ) and EH were calculated it appears that weaker EH were more likely to be the cause of the asymmetry. There was also a marked dom:ndom asymmetry for EH amongst the youngest age group which was not immediately explicable, though the same trend was not apparent for CQ and CH. None of the papers included in Table 2.2 included any information regarding AoPT.

Regarding the effect of biological ageing on isokinetic muscle strength and performance, only Holm, Steen and Olstad (2005) have considered this specifically in youth football. They concluded that maturation resulted in increased CQ and CH PT, though much of the observed difference was removed by applying a BW ratio adjustment. CHQ was not considered directly by Holm, Steen and Olstad (2005) though it was possible to calculate from the data presented. CHQ ranged between 0.62 and 0.68 across the five pubertal groups and no changes were greater than 0.06. This biological age effect was not isolated from that of chronological ageing in the Holm, Steen, Olstad (2005) study which again highlights the difficulty of separating the inherent developments attributable to either chronological or biological ageing.

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Information existed regarding PT and muscular performance of the hamstrings and quadriceps throughout chronological ageing in youth footballers, though information which related to the effect of biological ageing was scarce. Only one paper to date (Kellis et al., 2001) has considered PT as well as other muscular performance factors in a number of chronological age groups representative of the way competition and training in youth football is organised through clubs. The Kellis et al. (2001) paper also utilised Greek youth footballers and so it should be considered that the training and expectations of youth footballers, as dictated, monitored and regulated by national bodies (for example the FA in England) could be different across countries. This means that to date, very little comprehensive information exists regarding the isokinetic PT and muscular performance of youth footballers participating in training and games in England. Thus, the final phase of this section of the review of literature discussed the nature of the English 'academy/centre of excellence' football and the demands of football at youth level.

Muscular	Author (year)							Age (year	s)				
performance variable			10	11	12	13	14	15	16	17	18	19	20
CHQ	lga et al. (2009)#	dom	-	-	-	-	[	0.55	]	-	-	-	-
		ndom	-	-	-	-	[	0.52	]	-	-	-	-
	lga et al. (2006)	dom	-	-	[	0.57	]	-	-	-	-	-	-
		ndom	-	-	[	0.56	]	-	-	-	-	-	-
	Amato et al. (2003)*	dom	-	-	-	-	-	[0.6	50]	-	-	-	-
		ndom	-	-	-	-	-	[0.5	56]	-	-	-	-
	Kellis et al. (2001)	dom	0.66	0.67	0.62	0.63	0.65	0.63	0.63	0.66	-	-	-
		ndom	0.65	0.60	0.60	0.61	0.62	0.65	0.60	0.64	-	-	-
	Lehance et al. (2009)	dom	-	-	-	-	-	[0.	63]	-	[	0.60	]
		ndom	-	-	-	-	-	[0.6	61]	-	[	0.61	]
FHQ	lga et al. (2009)#	dom	-	-	-	-	[	0.68	]	-	-	-	-
		ndom	-	-	-	-	[	0.65	]	-	-	-	-
	Kellis et al. (2001)	dom	0.94	0.85	0.87	0.81	0.81	0.89	0.81	0.79	-	-	-
		ndom	1.29	0.82	0.83	0.76	0.81	0.86	0.76	0.80	-	-	-
dom: ndom	lga et al (2009)#	CH:CH	-	-	-	-	[	1.02	]	-	-	-	-
		CQ:CQ	-	-	-	-	[	0.96	]	-	-	-	-
	lga et al. (2006)	CH:CH	-	-	[	1.03	]	-	-	-	-	-	-
		CQ:CQ	-	-	[	1.02	]	-	-	-	-	-	-
	Amato et al. (2003)*	CH:CH	-	-	-	-	-	[1.0	)8]	-	-	-	-
		CQ:CQ	-	-	-	-	-	[1.0	)0]	-	-	-	-
	Kellis et al. (2001)	CH:CH	1.03	1.07	1.06	1.06	1.07	1.08	1.04	1.04	-	-	-
		CQ:CQ	1.02	0.96	1.03	1.01	1.02	1.02	1.00	1.01	-	-	-
		EQ:EQ	0.99	1.00	1.02	1.03	1.05	1.06	1.00	1.07		-	-
		EH:EH	1.02	0.78	0.78	0.85	0.84	0.83	0.83	0.84		-	-
AoPT	-		-	-	-	-	-	-	-	-	-	-	-

Table 2.2. Hamstrings and quadriceps muscular performance in youth footballers at 60°/s

\*Values taken from 2001 results. (------) illustrates that the data is the mean for a chronological age group larger than one year. #data for conventionally trained youth footballer

#### 2.3.3. Youth football in England

Estimated participation rates have suggested that 1.75million English boys participate in 'frequent' (at least 10 occasions per week) football activity (Malina, 2005). In addition, talented and elite youth footballers registered to English academies and centres of excellence aged eight to 16 years number approximately 10,000 (Simmons, 2001 cited in Malina, 2005). Academy and centre of excellence structure undoubtedly varies between clubs, but in general the following will apply: at least one coach per age group (under nine (U9) - under 18 (U18)), U12 engage solely in small sided time restricted games and play no more than 30 games per season, U13 and over may play 11 a-side football for between 24 and 30 games per season and all age groups U16 will train between two and four times per week (Stratton et al., 2004). In addition, U12 players must live within a 60 minute journey of their club, while U13 to U16 must live within 90 minutes. This is to ensure that the young player's academic and personal education is not adversely affected by their football education (Stratton et al., 2004). Stratton et al. (2004) reported that academy and centres of excellence conform to a curriculum which broadly includes 1) technical and tactical football components, 2) physical component, 3) psychological awareness, 4) diet and nutrition, 5) competence skills and 6) academic and/or vocational component. This curriculum was of interest because muscular strength and performance may be affected by some or all of these areas of intended player development. Therefore an understanding of the physiological, biomechanical and psychological demands of training for youth football was important. Also of particular interest from physiological and biomechanical perspectives were the specific football development goals which coaches work towards during training with players at differing stages of chronological and biological ageing. A possible model to explain this was the soccer development model (SDM) of Wein (2001), and also the long-term athlete development model (LTADM) proposed by Balyi and Hamilton (2000). Both of these models acknowledge that the essentials of training for sport lie in fundamental movement, technical skill, and fitness acquisition and development (Stratton et al., 2004). Therefore, the next phase of the current literature was to review chronological age group specific activities and demands with reference to the areas of the typical academy/centre of excellence curriculum as outlined above.

## 2.3.4. Football training at less than 10 years

The SDM (Wein, 2001) suggested that before the age of 10 years youth footballers should focus upon skills and incorporate small group drills and small sided (2 vs. 2, 4 vs. 4, 8 vs. 8), time restricted games. The LTADM (Balyi and Hamilton, 2000) suggested technical development at this time should also progress from fundamental movements to basic sporting skills. These goals feed into the academy curriculum by meeting the need for early stage football components, with some academies/centres of excellence even employing specific technical instructors to meet this unique

demand (Stratton et al., 2004). In addition, Burwitz (1997) argued that in youth football coaching greater emphasis is placed upon skill which is goal rather than process driven, thus the player who can complete a 'good' pass may be more valued than the one who can demonstrate the perfect passing technique. This suggests that even at the earliest stages of football training and development, performance is valued and as such possible contributors to good execution such as muscular strength may be important.

Jones and Drust (2007) offered insight into the physiological and technical demands of football activity at this age, concluding that physiological demand (as measured by heart rate and total distance covered) were not significantly greater in four vs. four than eight vs. eight games in their sample of eight male youth footballers (aged 7 ± 1years). Additionally neither the mean respective total distances covered by players (778m vs. 693), the distances spent completing walking (181m vs. 187m), jogging (315m vs. 334m) and sprinting (143m vs. 71m) were different (Jones and Drust, 2007). However the technical aspects of the football activity (as measured by number of ball contacts) were significantly different because reducing the number of players in the game increased the amount of contacts per individual (8 vs. 8: 13, 4 vs. 4: 36). These findings validate the suggestion of Wein (2001) that coaches may use small sided games to increase the technical demand of training for younger age groups without also increasing the physiological demand upon an immature neuro-musculoskeletal system. This increased demand for technical aspects in training could be postulated to manifest as a difference in the muscular strength and performance between the dom and ndom legs at this age group because of the documented preference of elite footballers to preferentially complete skill activities with their dom leg (Fousekis, Tsepis and Vaganas, 2010).

#### 2.3.5. Football training at 10 to 14 years

The LTADM (Balyi and Hamilton, 2000) described this age range as the 'training to train' and start of the 'training to compete' phases whereas the SDM (Wein, 2001) suggests the introduction of a group and individual 'testing' component from age 12. Both authors highlight the need for continued specialist skill development but introduce the concept of tactics and physical and mental fitness. Thus, it can be seen that physical parameters for performance are introduced, tested, developed and monitored by coaches. Adolescence is often seen as a period where physical training and performance goals may be achieved to good effect; however there is little evidence to suggest that the effects of physical training on performance are specific to the mode of training employed at this age (Stratton et al., 2004). This was evidenced by Berg, LaVoie and Latin (1985) who found that in their sample of 20 school footballers training and playing football for nine weeks resulted in better physiological performance (as measured by maximal oxygen consumption (VO<sub>2</sub> max) and sub-maximal running) but no increases in quadriceps PT or flexibility

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of the hip flexors. Stroyer, Hansen and Klausen (2004) also reported that in their comparison of elite and non elite youth footballers pre (12 years) and post puberty (14 years), the elite players who trained more intensively had better physiological performance (as measured by VO<sub>2</sub> max) post puberty than the non elite. In addition, the data of Stroyer, Hansen and Klausen (2004) suggested an effect for positional difference and specialised training because the midfield and attacking players outperformed defenders.

The aforementioned literature serves as evidence of the physical and physiological demand of playing and training soccer increasing with chronological ageing, possibly resulting in increased performance as a result. However, as previously alluded to, it should be considered that the male footballers who form the 'elite' samples may do so because of 'self-selection', pre-disposition and ability to improve and perform well when compared to non elite athletes. This may be as a result of early maturation or even the 'relative age effect' that suggests that many elite youth footballers have birth dates in the first quarter of the academic year, are biologically more mature and slightly chronologically older than their peers (Stratton et al., 2004); thus, resulting in an 'elite' sample which is more advanced regardless of training effects. This is an important consideration for the current project because it may suggest some rationale for the differences between the youth football population and the non sport-specific population highlighted earlier in the review.

## 2.3.6. Football training at greater than 14 years

At greater than 14 years the LTADM (Balyi and Hamilton, 2000) outlined that at ages 14-17 years there should be an increased focus upon 'training to compete', and at 17-18 years+, the focus should shift toward 'training to win'. This change in approach is encompassed by a greater focus upon training time and advancing individual: tactical awareness and appreciation, specialist skill, physical and mental preparation and capacity, and sport specific performance as a whole. The SDM (Wein, 2001) suggests activities which focus on collective training and individualised training for position as well as detailed game strategy and tactics. This accompanies longer game time and a move to 11 vs. 11 football games. It should also be again noted that in the English system players aged 16 (playing at U16 level competitively) may be offered a full time scholarship which can register a player with a club until his 19<sup>th</sup> birthday, though it usually includes an option to maintain that registration until the age of 21 (Stratton et al., 2004). Players then compete at under 18 (U18) and reserve competitive standard, and at any time after the age of 16 a player may also be offered a full time professional contract (Stratton et al., 2004).

For this oldest age group there was literature available that considered a biomechanical analysis of the demand imposed by typical football training drills (Sainz and Cabello, 2005), and of the

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lactate threshold responses over the course of the season (McMillan et al., 2005). Sainz and Cabello (2005) reported biomechanical data (as measured by digitised video analysis) of distance covered and linear velocity for 10 elite U19 Spanish youth players during three different training drills. They concluded that the average distance covered in the drills was 711m with average percentages of standing still/walking (13.7%), jogging (53.3%), medium intensity running (27.4%), high intensity running (5.2%), and sprinting (0.34%). The authors stated that the biomechanical demand was slightly higher than would be expected of adult players over 90 minutes of football, however, the physiological demand (as calculated by heart rate) was comparable to the professional game (Sainz and Cabello, 2005). Unfortunately, these authors did not provide any data regarding the technical demands in terms of number of ball contacts. In addition, McMillan et al. (2005) reported training data for 37 elite male youth footballers (mean age 18.3 years) over the course of one competitive season. As part of their analysis these authors undertook a review of the time spent in different activities over the course of the season (Table 2.3).

Activity	Average hours spent completing type of activity each week (hr/week)							
	Pre-season (June) -	October - December	January - March	March - June				
	October							
Warm Up	1.67	2.17	1.67	2.17				
Stretching	1.5	1	1	1				
Endurance Running	3	1.5	1	0.5				
Small Sided games	2.5	1.75	2	1.25				
Technical training	1	1.5	1.5	1				
Strength Training	1	1	1	0.5				
Match Play	1.5	1.5	2.25	3				
Total	12.2	10.4	10.4	9.4				

Table 2.3. Overview of football training activity over the course of a competitive season

(McMillan et al., 2005)

Table 2.3 suggests that training mode and intensity for this age group were variable across the season, which may impact upon the expected seasonal variation of muscular strength and performance; however this was not measured by McMillan et al. (2005). McMillan et al. (2005) measured lactate threshold responses and reported that their sample improved their aerobic endurance (as measured using lactate levels during a sub maximal treadmill protocol) during pre season, which was comparable to adult footballers. The assertion that the results were again comparable to physiological measures taken of the adult professional players was of interest because it suggested that once academy/centre of excellence footballers undertake full time training and competition their physiological performance may be equal to that of adults.

There was a dearth of information regarding the biomechanical and technical demands of playing and training for football in the older academy age groups. However, the aforementioned comparability to the adult game in physiological data and training effects suggested that a review of the biomechanical and technical demands of the adult game may also prove informative for the current review of literature. Thus, a brief evaluation was undertaken below.

#### 2.3.7. Biomechanical and technical analysis of football

The biomechanical factors relevant to success in football were reviewed by Lees and Nolan (1998). They stated that the skill of kicking a football is developed throughout ageing and maturation in addition to other technical aspects of the game. Kicking is an asymmetric skill which relies upon complex interactions between technique, speed and the demand for accuracy (Fields et al., 2005; Lees and Nolan, 1998). The two main kicking techniques are the side foot kick and instep kick; both allow the player to kick the football with power and accuracy (Brophy et al., 2007). Neuro-muscular co-ordination and muscular power of the muscles of the hip and thigh provide the majority of the propulsive force needed (Lees and Nolan, 1998). In addition, joint motion of the lower limb during kicking also relies upon simultaneous activation of antagonist/agonist and concentric/eccentric muscle pairings and actions (Kellis and Katis, 2007). However, the majority of authors acknowledge that successful performance of this skill relies upon far more than muscular performance, citing decision making and 'reading the game' as other possible factors (Lees and Nolan, 1998). Thus, it may be that in older players increased chronological age could have an advantage compared to their younger peers in these psychological and decision making skills (Fragoso et al. 2005).

Lees and Nolan (1998) highlighted a lack of football specific biomechanical analysis into other common football actions such as: passing and trapping the ball, starting, stopping, changing direction and dribbling the ball. However, information regarding the technical demands, in terms of the frequency of these additional actions, of the professional game was available for the English premier league (Rahnama, Reilly, and Lees, 2002). This is illustrated in Table 2.4 which included event information which was ball specific and therefore actions such as time spent walking, jogging, running, cutting and sprinting were not included. This was because actions such as passing the ball and receiving the ball were reported to be by far the most often occurring (Rahnama, Reilly, and Lees, 2002), it should also be noted that these actions are also normally unilateral (Lees and Nolan, 1998).

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Playing action (ball involved only)	Amount of events per game	
Dribbling the ball	15.7	—
Goal catch	23.0	
Goal Punch	4.3	
Goal Throw	8.1	
Heading the ball	172.3	
Jumping to head	122.5	
Kicking the ball	233.0	
Making a tackle	91.0	
Making a charge	58.5	
Passing the ball	414.5	
Receiving the ball	368.8	
Receiving a tackle	91.0	
Receiving a charge	58.3	
Shot on goal	82.0	
Set kick	67.6	
Throw in	50.9	
Total	1787.7	—
	(Rahnama, R	eilly and Lees, 2002

Table 2.4. The technical demands of the English premier league

#### 2.3.8. Summary

This review of the isokinetic muscular strength and performance of youth footballers confirmed that youth footballers show linear increases in PT of the hamstrings and quadriceps as they age chronologically and biologically. When compared to 'normal' non sport-specific individuals there were distinct differences for CQ PT/PTBW because youth footballers appeared stronger. There was also a suggestion of lower PT CH after the age of 13 years for youth footballers though this remains to be substantiated. A further finding of the review was that there was no specific muscular strength data for many of the age groups of English youth footballers who undergo a structured training development regimen at academies and centres of excellence across the country. Data regarding the muscular performance of youth footballers was also scarce, with no current information at all existing for AoPT and very little data for muscle balance and dom:ndom asymmetry. It was noted that nearly all literature considering the performance of youth footballers did so using chronological rather than biological age comparisons which probably reflects the logistical organisation of youth football, however there may be a relative age effect upon the data considered. Unfortunately, information regarding the demands of training and playing football at youth level was also particularly limited. It was clear that academies and centres of excellence in England appear to deliver a fairly structured programme of football education. Unfortunately, there remains a significant lack of objective data regarding the demands of the youth football game physiologically, psychologically and biomechanically. It was difficult to link the demands of the youth game to the muscular strength and performance normative data discussed earlier in the review as there was no clear answer to the question of whether the muscular performance of youth footballers is inherent or developed as a result of their involvement in training.

#### 2.4. The relationship between strength, muscular performance and injury in youth football

This third section of the literature review considered injury in youth football and the possible relationships with chronological and biological ageing, and muscular strength and performance. This allowed for progressive research questions to be derived and investigated as part of the current project. In order to generate research questions, the initial concern was to evaluate the 'problem' caused by injuries in youth football. This was important because in contrast to the adult game the consequences of injuries in youth are usually evaluated in terms of damage to player career development (Price et al., 2004). Therefore, even though youth football has been cited to have approximately half the injury incidence of the adult/professional game (Price et al., 2004), the frame of reference for research and possible prevention may be quite different. The problem of injury in youth football may also differ over age groups and competition level. Additionally, age groups may contain individuals who are at differing stages of muscular strength development, growth and maturation, though in order to progress through the English academy system they participate according to their chronological age.

After information regarding the prevalence, consequences and seriousness of injury in youth football had been gathered and reviewed the possibilities for injury risk attenuation were considered. This consisted of discussion of the nature (type, location, timing and mechanism) of injury and the possibilities for prevention through risk attenuation according to whether it would be modifiable. This process allowed for a specific area of interest: the prevalence, risk and prevention of hamstring muscle strains in youth football. A large driver for this area of concern was that these injuries have been reported as very common in English academy football and may be caused by strength deficits (Price et al., 2004) and thus links to the analysis of strength development throughout growth and maturation. In addition, muscle strains (particularly strains of the hamstrings) are likely to re-occur, becoming the most common injury in adult footballers (Hawkins et al., 2001) which could highlight a need for prevention in the early career of many footballers.

The final focus of the review of literature in this section was to critically evaluate proposed injury prevention strategies for hamstring and quadriceps muscle strains in football, and to identify those which might be usefully transferred to youth footballers. The review also allowed analysis of the varied designs which have been used to investigate injury prevalence and prevention allowing for conclusions regarding the most appropriate and effective protocols. This contributed substantially to the methodology of the current project in later chapters.

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#### 2.4.1. Introduction to injury in elite male youth football

For the purposes of the subsequent review injury was defined as: "any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities" (Fuller et al., 2006, pp 193).

This definition was in line with the consensus statement on injury definition and data collection in studies of football (Fuller et al., 2006). The rationale for these recommendations was to improve the quality of research in the field of injury in football and to provide a platform to allow increased comparability across studies (Fuller et al., 2006). In line with this literature, it was decided that injury incidence should be reported as a ratio of 1000 player hours spent completing training or playing football, termed 'football activity' and that injury severity be measured in days of missed football activity (Fuller et al., 2006). Fuller et al. (2006) also advocated that injury recording should take into account the classification (full diagnosis), type, location, timing and mechanism of injury, as well as clearly state the study population and each player's baseline information. There should also be separate provision for injuries which are reported to club medical staff (RI) and those which result in days of lost training or game time (time loss injury; TLI: Fuller et al., 2006). Unfortunately, though the above recommendations may be encompassing, they may present a logistical impasse. If an injury is not reported, does not require evaluation or treatment, and does not cause the player to 'miss' any football activity the researchers/medical team would not be aware of the injury to include it in their data collection (Junge et al., 2004).

The problem of injury in youth football may be considered a product of injury incidence and severity. These factors were therefore investigated through the creation of Table 2.5 (pp 38-39) which amalgamated: classification, type, location and causality of injury for studies of male youth footballers since 1978. Chronological and biological age comparisons, severity and timing of injury and re-injury were also discussed where appropriate. As previously, and for similar reasons, only information regarding the injuries sustained by club and elite level footballers was included in this table. This was to ensure that the youth football population remained a distinct entity and that there was no overlap with high school players who may not train as specifically or intensively. This led to exclusion of papers such as Yard et al. (2008) who investigated USA high school soccer injuries for two seasons, papers released by the national collegiate athletic association (NCAA) and other papers where the information presented did not clearly differentiate between male and female data (Emery and Meeuwisse, 2006; McCarroll, Meany and Sieber, 1984), or adult and youth data (Schmikli et al., 2011; Yoon, Chai and Shin, 2004), or different sports (Maffulli, Baxter-Jones and Grieve, 2005).

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Author Study setting/ F (Date) Length of		Population concerned	Injury incidence	Injury severity (as per study	Commonly reported of injury (as		per study methodology	Other important information	
• •	U	(participant number)	(as per method)	definition) days out (%)	Classification	Туре (%)	Location (%)	Mechanism (%)	
Le Gall et al. (2006)#	Multiple seasons (10)	U14-U16 (n = 528)	4.8/1000 hours, 2.2/player/ season	1-3 = (31.0), 4-7 = (29.3), 7-28 = (29.9), 29+ = (9.9)	-	Contusion (30.6); Sprain (16.7); Muscle Strain (15.3)	Upper leg (24.5); Ankle (17.8); Knee (15.3)	-	-
Emery, Meeuwisse & Hartman (2005)#	Season long analysis (13 weeks)	U14-U18 (n = 153)	5.6/1000 hours	≤1 = (49.3), 2-7 = (34.8), 8-14 = (11.6) >14 = (17.4)	Ankle Sprain (29.0); Groin & Calf strain, Concussion (9.7)	-	Lower limb (74.2): Ankle (29.0); Lower leg (16.1); Knee (12.9).	-	Included assessment of maturation
Kirkendall, Marchak and Garrett Jr (2005)	Multiple seasons (3)	U12-U18 (n = 7589)	5.1/1000 exposures	-	-	-	Ankle (22.0); Knee (15.3); Leg, shin/calf (9.3).	-	Coach reported Injuries. Exposure by sessions
Kucera et al. (2005)#	Multiple seasons (3)	U12-U18 (n = 929)	4.3/1000 hours	-	-	Ankle Sprains (20.5) Knee Sprain (9.9)	-	-	Coach reported injuries.
Malliou et al. (2005)	12 month analysis	age 16.5±1.5 years (n = 35)	30 RI/per year	<7 = (78.0), 8-14 = (11.0), 15+ = (11.0)	Ankle sprains (40.0); Knee ligament sprains (26.7); Adductor strains (13.3)	-	Knee (46.6); Ankle (40.0)	-	-
Rahnama & Manning (2005)#	6 month analysis	age 17.0 ± 0.8 years (n = 24)	3.2/1000 hours	Slight = (3.0) Minor = (16.0) Moderate = (52.0) Major = (29.0)	-	Strains (29.0); Sprains (26.0); Contusions (29.0)	Ankle (28.0); Foot (13.0); Hip (13.0)	Running/striking/ turning (42.0)	Questionnaire design
Junge et al. (2004)	6 month analysis	14 - 18 years (n = 145)	27.9/1000 hours	0 = (69.3), 1-7 = (19.9), 8-21 = (7.3) >21 = (3.4)	-	Strain (31.8); Sprain (20.3); Contusion (28.4)	Ankle (17.2); Thigh (17.0); Lower leg (16.1)	Contact (48.3)	Training: game 1.6:1
Price et al. (2004)	Multiple (2) season analysis	U9-U19 (n = 4773)	0.40/player/ season	1-3 = (10.0), 4-7 = (23.0), 8-28 = (44.0) 29+ = (22.0)	Thigh muscle strains, MCL & ATFL sprains.	Strain (31.0); Sprain (20.0); Contusion (8.0)	Thigh (19.0); Ankle (19.0); Knee (18.0)	Running (19.0); Tackled (15.0)	All English academy clubs
Kakavelakis et al. (2003)#	10 month analysis	12-15 years (n = 514)	4.0/1000 hours	<7 = (30.0), 8–28 = (38.0), 29+ = (32.0)	-	Sprain (33.0); Strain (23.0); Contusion (21.0)	Lower limb (84.0): Knee (36.0); Ankle (29.0)	Contact (40.0)	Physician diagnosis. Only included RI

# Table 2.5. Research papers concerning injuries in youth football

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_										
	Junge et al.	Multiple (2)	age 16.5 ±	8.5/1000	<7 = (60.0), 8 – 28 =			Thigh		Comparison of
	(2002)#	season	1.2 years	hours	(20.0), 29+ = (14.0)	-	-	(0.26/player/year),	-	groups.
		analysis	(n = 194)					Knee & Ankle		
_								(0.19/player/year)		
	Junge et al.	1 year	14-16 & 16-	2.5/1000	7-14 = (40.2), 8-21 =			Ankle (25.3); Knee		European region
	(2000)#	analysis	18 years	hours	(33.5), 28+ = (26.4)	-	-	(22.7); Thigh (15.5)	-	compared. Self
_			(n = 311)							report design
	Peterson et	1 year	14-16 & 16-	9.5/1000	<7 = (23.0), 8 – 28 =			Lumbar spine (27.3);		Considered
	al. (2000)#	analysis	18 years	hours	(30.0), 29+ = (29.0)	-	-	Ankle (24.1); Head	-	injuries, not
			(n = 177)					(20.1)		related to
_										football
	Kibler	Multiple (2)	480 game	2.3/1000	1 <sup>st</sup> degree = (24.5)		Contusion (32.0);	Thigh (21.0); Knee	Contact (56.3);	Participant
	(1993)	tournament	analysis	hours	2 <sup>nd</sup> degree= (21.8)	-	Strain (24.5); Sprain	(15.8); Ankle (13.0)	Tension overload	demographics
_		analysis			3 <sup>rd</sup> degree = (8.0)		(21.8)		(20.4)	unclear
	Schmidt-	10 month	12- 13, 14-	3.7/1000				Lower limb (70.0);		Self report
	Olsen et al.	analysis	15, & 16-18	hours	-	-	-	Knee (26.0); Ankle	-	design
	(1991)#		years					(23.1)		
_			(n = 496)							
ω	Yde and	9 month	<10, <=14,	5.6/1000	<14 = (57.0), 14 -			Ankle (27.0), Thigh	Tackling (41.0),	Self report
9]	Nielsen	analysis	<=18 years	hours	28 = (19.0), 29 -42 =	-	-	(24.0)	Running (27.0)	injury defined by
_	(1990)#		(n = 152)		(13.0), 42+ = (11.0)					time loss
	Neilsen &	11 month	16 -18 years	9.1/1000				Ankle (% unclear)	Tackling (48.0)	Injuries reported
	Yde	analysis	(n = 30)	hours	-	-	-			by coach
_	(1989)#									
	Schmidt-	International	9 -11, 12-	16.1/1000	0 = (0.0) Advised		Skin complaint,	Thigh, Ankle, Knee,		Game only
	Olsen et al.	Tournament	13, 14-16,	hours	reduced		contusion, Sprain,	Foot (all % unclear)		Included illness
	(1985)		17-19		activity/hospital	-	Strain (% unclear)		-	and injury
			(n = 5275)		treatment needed =					Only RI included
_					(2.6), Serious = (0.4)					
	Sullivan et	Season	U8 - U19	0.5/1000						Injuries reported
	al. (1980)	'spring'	(n = 931)	hours	-	-	-	-	-	by coach/parent
_										
	Nilsson &	International	12- 13, 14-	Approx						Skin abrasions
	Roaas	Tournament	15, & 16-18	14.0/1000						removed from
	(1978)	(x2)	years	hours	-	-	-	-	-	RI's
_			(n ~ 25,000)							

Abbreviations used in Table 2.5: reportable injury (RI) medial collateral ligament (MCL), anterior talo-fibula ligament (ATFL). # = Studies which did not contain anomalous or data or have questionable reliability

#### 2.4.2. Injury incidence

The injury incidence reported in male youth footballers ranged between 0.5 injuries /1000 hours of football activity (Sullivan et al., 1980) and 27.9 injuries /1000 hours of football activity (Junge et al., 2004) with an average across 17 of the studies of 7.5 injuries /1000 hours of football activity. Only Malliou et al. (2005), Kirkendall, Marchak and Garrett Jr (2005) and Price et al. (2004) used a system different than that advocated by Fuller et al. (2006) for reporting injury incidence, possibly due to the earlier publication dates. These authors simply reported: the number of injuries reported (Malliou et al., 2005), injuries per number of exposures, or injuries per player per season (Price et al., 2004). Malliou et al. (2005) and Price et al. (2004) both failed to record exposure to football activity making the injury/exposure (hours) calculation impossible, and Kirkendall, Marchak and Garrett Jr (2005) simply recorded the number of sessions rather than counting hours of activity. In addition, it should be considered that Le Gall et al. (2006), Emery, Meeuwisse and Hartman (2005), Rahnama and Manning (2005), Junge et al. (2004), Junge et al. (2002), Junge, Chomiak and Dvorak (2000) and Peterson et al. (2000) actually recorded exposure per player which was likely to be more accurate than the other authors (Kucera et al., 2005; Kakavelakis et al., 2003; and all of the studies from 1993 - 1978) who estimated exposure based on average training times and/or player numbers multiplied by number of games. This is important because if exposure is not accurately recorded, or over/under estimated it could inflate or deflate the perception of the total injury prevalence problem.

A further important consideration for the above studies was that some only included game analysis (Kibler, 1993; Schmidt-Olsen et al., 1985; Nillson and Roaas, 1978), which could have meant that their injury incidence figures would be abnormally high because it is accepted in the literature that competitive games have a higher injury incidence (per hours spent completing) than training (Le Gall et al., 2006; Wong and Hong, 2005; Junge et al., 2004, 2002; Junge, Chomiak and Dvorak, 2000). This would appear to be true for Schmidt-Olsen et al. (1985; 16.1/100hours) and for Nilsson and Roaas (1978; approx 14.0/1000hours). However, for Kibler (1993) this did not appear to be the case. Their analysis of 480 tournament games resulted in a surprisingly low (2.3/1000 hours) injury incidence. This anomalous result may be due to some over estimation of hours spent by each player fulfilling football games during the tournament, for example assuming all players played all games. Unfortunately, Kibler (1993) does not give enough methodological detail of the participants included in their study to allow definitive conclusions. Contrastingly, the injury incidence of Junge et al. (2004) may be considered high (27.9 injuries/1000 hours of football activity including training and games). This may have been due to the fact that the participants for their study had a much lower training to game ratio of 1.6: 1, meaning that for every match only 1.6 hours of training was undertaken, thus artificially increasing injury incidence.

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This training to game ratio was low in comparison to Junge, Chomiak and Dvorak (2000) and Petersen et al. (2000) who reported the same ratio as 4.6:1 and 3.3:1 in their samples of club youth footballers in France, Czech Republic and Switzerland. A final point for discussion was that the lowest injury incidence reported of (0.5 injuries/1000 hours, Sullivan et al., 1980) contained author estimates of players per team (x80 teams), and an assumed participation rate of 40 hours per season. Obviously this level of estimation requires caution regarding the accuracy and reliability of the published data.

With the anomalous or data of questionable reliability removed for the reasons given above the average injury incidence recorded by the literature included in this review (identified by # in Table 2.5, pp 38-39) was 5.5 injuries/1000 hours of football activity. This is slightly higher than one of the most comprehensive studies included in the review; Le Gall et al. (2006). Le Gall et al. (2006) analysed player injuries at a national youth football training facility for 10 years using a longitudinal design, however, the players involved in the study may not have been representative of English club-based youth footballers due to the full-time nature of the training facility. Le Gall et al. (2006) had the benefit of analysing data direct from medical reports injured players which was not the case for most of the studies included in this review. Kirkendall, Marchak and Garrett Jr (2005), Kucera et al. (2005), Junge, Chomiak and Dvorak (2000), Schmidt-Olsen et al. (1991), and Sullivan et al. (1980) relied upon player self-reporting or coach reporting of injuries either by questionnaire or by interview. This approach was highlighted by Fuller et al. (2006) as being subject to error during re-call and thus the results of these studies should also be interpreted with care.

In comparison to the adult game, 5.5 injuries/1000 hours of football activity may be considered low. Petersen et al. (2000) reported a figure for the adult footballers involved in their study of 9.8/1000 hours and Hawkins and Fuller (1999) reported 8.5/1000 hours for English players. Additionally, in England, Price et al. (2004) reported that youth players may be expected to sustain 0.4 injuries per player per season, whereas in the professional game this was reported to be 1.3 per player per season (Hawkins et al., 2001). The higher figure was hypothesised to be as a result of an increased number of overuse and degenerative injuries in the adult/professional populations (Petersen et al., 2000). Nonetheless the incidence of injury in youth footballers remains concerning, both from the perspective that development time and career aspirations may be damaged by injury (Price et al., 2004) and also the perspective that little is known about the possible detrimental long term health effects of injury in youth populations (Maffulli et al., 2010).

Overall, it was clear that injury incidence in youth football is lower than that of the adult/professional game, higher in competitive games than in training and may have an effect

upon future football performance and health. These points were in agreement with a comprehensive review on the topic (Wong and Hong, 2005). However, it is also clear that many methodological differences and reliability/validity issues also exist within the literature, meaning that few direct comparisons were possible. Also highlighted was the lack of a clear injury incidence/1000 hours of football activity for youth football in England, as only Rahnama and Manning (2005) and Price et al. (2004) studied this population. As previously stated Price et al. (2004) did not provide their incidence date as injuries/1000 hours of football activity though they completed a study of all English academy clubs and age groups. Unfortunately Rahnama and Manning (2005) used a relatively small sample size (n=24) which affected the transferability and external validity of their results. These factors suggested that further investigation into the injury prevalence in English academy/centres of excellence footballers was warranted.

#### 2.4.3. Injury severity

Table 2.5 (pp 38-39) shows that in the majority of previous literature injury severity has been presented as a categorical variable measured by days of missed football activity. The system of categorisation tended to be consistent according to the research body. For example, most of the studies undertaken by the Federation International de Association Football (FIFA) (Junge et al., 2002; Junge, Chomiak and Dvorak, 2000; Peterson et al., 2000) used categories of <7, 8-28, and 28+ days of 'missed' football activity. Junge et al. (2004) also included an additional zero days category because the methodology of that particular study used an on-site medical diagnosis rather than a weekly follow up by an assigned physician. In contrast, Price et al. (2004), who also used on-site medical staff for injury identification, stated that injuries which caused reduced participation for less than 48 hours may not have been reported because of the working practices of English academies. This discrepancy suggests that there may be some under reporting of injuries in youth football not resulting in missed football activity, which may link to the problem considered previously regarding RI and TLI and their respective definitions by Fuller et al. (2006). This may be especially true when considering the results of the Junge et al. (2004) study because they stated that 69.3% of the injuries reported fell into this grey area, and thus correspondingly the other TLI categories were lower.

Of the studies reviewed there was discrepancy regarding the most common category of injury severity. Many authors (Le Gall et al., 2006; Emery, Meeuwisse and Hartman, 2005; Malliou et al., 2005; Junge et al., 2004; Junge et al., 2002; Junge, Chomiak and Dvorak, 2000; Kibler, 1993; Yde and Neilsen, 1990) reported that the least severe category was the most common. Collating these findings would suggest that the majority of injuries in youth football cause a player to miss participation for up to 14 days. However, in both studies using English youth footballers (Rahnama and Manning, 2005; Price et al., 2004), the most common time loss period for injury was eight to

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28 days. Although, this was also true for the studies by Kakavelakis et al. (2003) and Peterson et al. (2000) whose populations varied across Europe. These inconsistencies may be partially attributed to the different categorisation systems. For example, those that used the eight to 28 day category generally had more distinction for less severe categories meaning that there was overlap between days seven and 14 for many studies. On the other hand it may suggest that in English youth football the majority of injuries cause players to miss participation for up to 28 days. This compares accurately with the findings of Price et al. (2004) who stated that on average each injury prevented football activity for 21.9 days, which represented (when calculated with their injury incidence of 0.4 injuries per player per season) 6% of the season where player development was not occurring. This calculation of total injury prevalence highlights that injuries are a substantial problem in youth football and may pose a threat to future career and performance development. Therefore, preventing injury could be seen as a priority for those involved coaching and training this population.

### 2.4.4. Injury classification

Few of the studies included in this review gave a specific injury classification with full diagnostic information. Of those that did (Emery, Meeuwisse and Hartman, 2005; Malliou et al., 2005; Price et al., 2004), the most common injury classification was an ankle ligament sprain, except in English youth football (Price et al. 2004) where thigh muscle strain injuries were as common as ankle sprain injuries. For ankle ligament sprains the most common site for injury was the lateral ligament complex (Price et al., 2004; ligament sprains 72% of injuries to the ankle, 83% involving lateral ligaments). For thigh muscle strains (31% of all injuries), 57% involved the hamstrings and 43% the quadriceps (Price et al., 2004). Knee ligament sprains were also cited as a common injury classification (Malliou et al., 2005), particularly the medial collateral ligament (MCL; Price et al., 2004). Knee and ankle ligament injuries are common in cutting and twisting movements, and can be associated with contact and non contact mechanisms of injury (Norris, 2000). Muscle strains are predominantly caused by 'tension' overload of the musculature and are often associated with non contact mechanisms for injury like running and sprinting (Norris, 2000). All of which are common actions during football, and actions which are coached as players develop (Wein, 2001).

## 2.4.5. Injury type

Commonly reported types of injury were: contusions, ligament sprains, and muscle strains (Le Gall et al., 2006; Rahnama and Manning, 2005; Junge et al., 2004; Price et al., 2004; Kakavelakis et al., 2004; Kibler et al., 1993 and Schmidt-Olsen et al., 1985). The most common type of reported injury varied between study design, for example both tournament based studies (Kibler et al., 1993 and Schmidt-Olsen et al., 1985) cited contusions, whereas the majority of the studies which

analysed training and games over a season reported muscle strains (Rahnama and Manning, 2005; Junge et al., 2004; Price et al., 2004). Only Kakavelakis et al. (2003) and Le Gall et al. (2006) reported more ligament sprains than muscular strains in their respective samples. In English football both studies agreed that the most common injury type was a muscular strain (Rahnama and Manning, 2005, 29%: Price et al., 2004, 31.8%) whereas Greek authors Kakvelakis et al. (2003) and Malliou et al. (2005) both reported ligament sprains. This gives rise to the possibility that there may be different physical and training demands in the youth game across nations and gives an indication as to the scope of the conclusions from this project.

## 2.4.6. Injury location

Many of the studies (Table 2.5, pp 38-39) reported the most common locations for injury to occur in male youth footballers and all agreed that the majority of injuries occurred in the lower limb. The knee ranging from 12.9% (Emery, Meeuwisse and Hartman, 2005) to 46.6% (Malliou et al., 2005), ankle ranging from 13% (Kibler, 1993) to 40% (Malliou et al., 2005), and thigh ranging from 15.5% (Junge, Chomiak and Dvorak, 2000) to 24% (Yde and Neilsen, 1990) were the most commonly cited locations for injury. Some authors also reported high injury incidence for the lower leg/calf (Emery, Meeuwisse and Hartman, 2005, 16.1%; Kirkendall, Marchak and Garrett Jr, 2005, 9.3%; Junge et al., 2004, 16.1%), the hip (Rahnama and Manning, 2005, 13%), the lumbar spine (Petersen et al., 2000, 27.3%). This was expected, as football at all levels is a sport dominated by lower limb activity and collisions (Lees and Nolan, 2002).

From this perspective, the symmetry of injuries to the dom and ndom leg were also of interest. Only Emery, Meeuwisse and Hartman (2005) and Price et al. (2004) made reference to this in their papers, with Price et al. (2004) documenting that the dom leg was injured in 54% of cases vs. 35% on the ndom. Emery, Meeuwisse and Hartman (2005) also stated that in their study relative risk analysis of participant baseline data and injury occurrence suggested that left leg dominant players may be at a higher risk of injury then right leg dominant players. However, the dom to ndom distribution of injuries in youth football would appear to be an area where further research is needed. Particularly since this type of injury pattern has rarely been found to be significant in adult professional players (Zakas, 2006; Tourny-Chollet, 2000; Oberg et al., 1986).

## 2.4.7. Injury aetiology/mechanism

Analysis of the causation of injury (aetiology and mechanism) in youth football was difficult because few authors have included this information in their studies. A possible reason for this was that many studies had limitations because the authors or medical personnel were not present at training and/or games. Therefore, injury data was provided by the coach or players after the event, usually weekly or monthly by questionnaire or interview (as noted in Table 2.5 pp 38-39). Those studies which provided a mechanism of injury largely restricted themselves to a categorical system of reporting which was either contact/non contact (Junge et al., 2004; Kakavelakis et al., 2003) or the activity which was taking place when the injury occurred, for example running (Rahnama and Manning, 2005; Price et al., 2004; Yde and Neilsen, 1990; Neilsen and Yde, 1989) or a mixture of the two systems (Kibler, 1993). Analysis of this information suggested that contact with an external source made up 40-56% of the injuries reported, specifically tackling or being tackled 15-48%. Running was the only non-contact activity represented, with two studies (Price et al., 2004; Yde and Neilsen, 1990) reporting this mechanism for 19 and 27% of injuries. While this information was of note, it was lacking in the specificity needed to direct the methodology and rationale of the current project.

#### 2.4.8. Timing of injury

Timing of injury was considered using two temporal parameters, the first being game specific by attributing the injury incidence to defined periods of a competitive game (for example minutes 0-15, 16-30, 31-45, 1<sup>st</sup> half extra time, 46-60, 61-75, 76-90, 2<sup>nd</sup> half extra time (Fuller et al., 2006)). Price et al. (2004) were the only authors to consider this variable in youth footballers and reported a pattern for increased injury incidence toward the end of competitive halves of play, peaking at 76-90 minutes. Price et al. (2004) did not discuss that in the younger age groups games do not last for the full 90 minute duration of the adult game. It is therefore possible that the data presented by Price et al. (2004) shows an exaggerated pattern because only the older age groups were included toward the end of halves, and the older age groups were also suggested to suffer more injuries than the younger players (Price et al., 2004). This indicates that the question of fatigue involvement in increased injury incidence requires further investigation before definitive links can be made between fatigue and injury in youth football.

The second temporal parameter considers injury incidence across the course of a competitive season. This analysis of seasonal variation has utility for the physiological and conditioning preparations of the players since periods of increased incidence can be compared to the training and game load at that time. Of the studies included in this review, only Le Gall et al. (2006) and Price et al. (2004) considered this variable. Both authors reported that injury incidence peaked immediately after a break in the normal training/playing routine. For Le Gall et al. (2006) this was characterised by a peak injury incidence (competition) during the month of September of 19.8/1000 hours which was the month after pre-season training in French football, though this was not stated to be significant. In similarity, Price et al. (2004) stated that the month before a break from football activity and the month of re-starting football activity (for example December – Jan, and July – August) were significantly different, in that the re-start of football

activity showed a higher injury incidence. Price et al. (2004) explained that this may be linked to inappropriate levels of conditioning for the sport, meaning that the football activity is too intense to allow the desired adaptations to occur and may result in tissue breakdown. It should be considered, however, that Price et al. (2004) did not measure player exposure in their study, which could mean that the exposure time to football activity increased and accounted for the observed differences.

#### 2.4.9. Injury across positions

There were few authors who considered this variable (Le Gall et al., 2006; Kucera et al., 2005; Rahnama and Manning, 2005; Price et al., 2004). Of these, Kucera et al. (2005) were the only authors to find nothing of note when comparing injury rate and injury history across the playing positions of the participants in their study. Conversely, Le Gall et al. (2006) and Price et al. (2004) both highlighted that in their studies, goalkeepers did not display the same pattern of injury type as outfield players. Goalkeepers tended to suffer a significantly greater number of upper limb injuries and significantly fewer ankle sprain injuries (Le Gall et al., 2006), and their injury incidence did not increase linearly with age (Price et al., 2004). However, the overall rate of injury incidence for playing position did not differ for either of these studies. Only Rahnama and Manning (2005) reported a significantly different injury incidence rate for wingers as compared to all other positions. Unfortunately, Rahnama and Manning (2005) only included two wingers in their sample, though this figure did comprise approximately 8.3% of their total cohort, thus suggesting that the external validity of the presented results was likely to be quite low.

Analysis of injury to playing position suggested that while a different pattern of injury type may exist, this may be largely attributable to the demands of the position in question because only goalkeepers may utilise their upper limb under the rules of association football. Of interest for the youth population was that goalkeepers may not be specialised to that position until later on in their youth career (Wein, 2001), and furthermore may not be subject to specific training in that position until specialism. This may suggest that injury prevention at youth level may also be justified in also not isolating this position.

## 2.4.10. Re-Injury

Only two studies included in this review considered the re-injury rate of the same anatomical structure (Le Gall et al., 2006 and Price et al., 2004) and interestingly both reported the same figure of 3%. Of this 3%, 65.8% (Le Gall et al., 2006) and 72% were recurring sprains and strains to predominantly the ankle and thigh. In addition, Le Gall et al. (2006) stated that of the recurrent injuries reported in their study nearly half (40%) resulted in a longer absence than the initial injury. Unfortunately, absence due to re-injury data was not available for English players involved

in the study by Price et al. (2004) because exposure time was not recorded. Also of importance was the finding of Kucera et al. (2005) that youth footballers who participated in their prospective cohort study who had sustained one previous injury were at twice the risk of a further injury (but not necessarily the same injury) during the period of analysis.

The aforementioned findings suggest that re-injury is not necessarily of high prevalence in youth football. However, it should be considered that this youth population is at the first stage of a potential career in football and so re-injury at this stage may represent the start of a chronic injury problem which could affect individual sporting performance for many years. Furthermore, injury may also cause direct or indirect participation cessation from sport and recreation at a young age, early onset osteoarthritis and can also interfere with psychological wellbeing (Abernathy and Bleakley, 2007).

## 2.4.11. Injury and chronological and biological age

For many of the studies considered, the highest number of injuries recorded during analysis occurred in the older age groups of competition (Price et al., 2004; Yde and Neilsen, 1990; Sullivan, 1980; Schmidt-Olsen, 1985). Of these only Sullivan (1980) was able to state that this was a significant finding. In contrast, Le Gall et al. (2006) and Schmidt-Olsen et al. (1991) found that the highest number of injuries in their studies occurred in the U14 and 12-13 year old players respectively. However, when injury incidence (per 1000 hours of football activity) was calculated both of these authors agreed that the older age groups in their studies (U16 and 16-17 year olds respectively) had the highest injury incidence. These findings would suggest that injury incidence and injury risk increase as a youth footballer progresses through the competitive age group system. However, in other studies the U14 age group (Emery, Meeuwisse and Hartman, 2005; Kirkendall, Marchak and Garrett Jr, 2005) and 14-16 year olds (Petersen et al., 2000) displayed the highest injury incidence when compared to older age groups. A possible reason for these discrepancies was that injuries may occur more readily as the competitive standard, or 'class' increases rather than simply the ageing of the participants (Kirkendall, Marchak and Garrett Jr, 2005). This would not appear plausible because of the results of Junge, Chomiak and Dvorak (2000) and Petersen et al. (2000) who both found that players of equal age category but playing at a higher skill standard sustained a lower injury incidence than those of a lower skill standard. It is therefore possible that these discrepancies in findings are caused by an additional factor which none of the previous studies mentioned in this review have considered, for example, differing maturation status of the participants.

Very few authors to date have completed research which considers the relationship between musculoskeletal injury and biological ageing. Only Broderic and McKay (2009), Johnson, Doherty

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and Freemont (2009), and Le Gall, Carling and Reilly (2007) have considered elite youth footballers. Only Johnson, Doherty and Freemont (2009) and Le Gall, Carling and Reilly (2007) completed controlled prospective trials. Interestingly, these authors gave opposing findings. Le Gall, Carling and Reilly (2007) stated that biological maturity did not significantly affect injury incidence in their sample of elite French youth footballers. In contrast, maturity was a useful predictor of injury in an English premier league academy (Johnson, Doherty and Freemont, 2009). Le Gall, Carling and Reilly (2007) described descriptive and specific between group differences such as: the higher incidence of strains and sprain type injuries in early maturing players, the significantly higher incidence of major injuries and osteochondral disorders in late maturing players, and the significantly higher incidence of tendinopathies and groin strains in early maturers. Le Gall, Carling and Reilly (2007) explained their findings by postulating that the early maturing participants in their study may use risk taking behaviour more readily than the late maturing individuals, and in addition they are already biologically older and may have greater BW. Both risk taking, and increased stature have been linked to higher injury incidence (Arnason et al., 2004; Linder et al., 1995). For late maturing participants Le Gall, Carling and Reilly (2007) stated that the increased prevalence of tendinopathies and osteochondral lesions was probably related to 'overuse' of these anatomical structures at a time of relative skeletal vulnerability. In this context 'overuse' may be considered as playing at an advanced chronological age standard in comparison to actual biological age. Johnson, Doherty and Freemont (2009) used a regression analysis to model biological maturity, playing hours and training hours with injury incidence, which explained 48% of the variance in the sample. They found that youth footballers who displayed the largest difference between their chronological age (and therefore standard of competition; including early or late maturers) and their biological age (classified by skeletal age in this study) were at an increased risk of injury when they trained and played football.

Thus, though it would initially appear that the aforementioned authors were disparate in their findings, closer inspection would suggest that biological maturity did have a relationship with injury in both studies. Despite this, conclusions regarding the relationship between injury and maturity in elite youth football may still be tentative at this time because other youth sports such as American football have clearly reported no relationship between biological maturity and injury (Malina et al., 2006). For clinical application, both Johnson, Doherty and Freemont (2009) and Le Gall, Carling and Reilly (2007) recommended that coaches and trainers make allowances for maturation differences by matching players of similar biological age where possible. Johnson, Doherty and Freemont (2009) also suggested that competitive groupings should be made via skeletal rather than chronological age while Broderick and McKay (2009) and Le Gall, Carling and Reilly (2007) deemed this impractical and unnecessary. The different methodologies used above

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were of great interest to the current project because injury aetiology is unquestionably multifaceted (van Mechelan, Hlobil and Kemper, 1992) and a regression approach may better reflect complex causality.

## 2.4.12. Summary

This section of the present review of literature suggested that injuries are a problem in youth football, yet occur to a lesser extent (incidence and severity) than in the adult professional game. The most common types of injury reported were strains and sprains, and the most common locations for injury were the ankle, knee and thigh. On the whole (when contusions were excluded) the most common specific diagnoses of injury were ankle ligament sprains and muscle strain injuries to the thigh, this was particularly true in English youth footballers. Injury incidence appeared to increase with chronological ageing and though some studies disputed this finding, the increase in incidence could not be wholly explained by differences in the standard of play alone. There appeared to be some relationship between biological maturity and specific types of musculoskeletal injury, though the evidence for this relationship was not yet considered strong enough to warrant a change in the pattern of progression through the academy youth system by the majority of authors. The implications of this review for the current project were that injury was a problem in elite youth football and as such prevention of injury should be a priority due to the implications on player development and each individual's football career prospects. Thus, the next step was to consider the preventability of injury in this population by considering injury risk.

## 2.5. Preventing injury

The previous sections of this review highlighted that youth footballers would benefit from research and intervention strategies aimed at injury prevention. Identifying an effective strategy for the prevention of injury may be achieved through following a theoretical sequence which is outlined below (van Mechelan, Hlobil and Kemper, 1992).



(van Mechelan, Hlobil and Kemper 1992)

Figure 2.4. The 'sequence of prevention' of sports injuries

This sequence encourages the researcher or clinician to use a logical and reasoned method for sports injury prevention, an approach which is echoed through this review of literature. Information regarding the prevalence and nature of the injuries reported in youth football may be seen as fulfilling the first, and partially fulfilling the second step of the cycle (Figure 2.4). Alongside this cycle the actual 'preventability' (Parkkari, Kujala and Kannus, 2001) of injuries in sport must be considered to complete the second step. This requires a detailed assessment of injury aetiology and mechanism followed by discussion of what 'risk' factors may predispose an individual to a higher chance of an injury occurring (Bahr and Krosshaug, 2005), and also an appreciation of whether this factor actually can be modified by clinical strategies. To aid this process, risk factors may be considered as internal to the individual, or external to the individual (van Mechelan, Hlobil and Kemper, 1992), examples are given in Table 2.6.

Table 2.6. Examples of internal and external, and modifiable (ivi) and non-modifiable (ivi)	Table 2.6. Ex	amples of interna	I and external, and	d modifiable (M)	and non modifiable	(NM)
---------------------------------------------------------------------------------------------	---------------	-------------------	---------------------	------------------	--------------------	------

Internal Factors	External Factors			
Physical defect/dysfunction	Sport Factors			
Physical Fitness  Aerobic endurance (M)  Strength (M)  Speed (M)  Skill (M)  Co-ordination (M)  Flexibility (M)  Previous injury (NM)  Psychological Factors  Physical Build  Age (NM)  Sex (NM)	<ul> <li>Type</li> <li>Exposure (M)</li> <li>Nature (e.g. collision)</li> <li>Action of opposition (NM)</li> <li>Action of team mate/s (NM)</li> <li>Action/Non action of officials</li> <li>Venue <ul> <li>Lighting (M)</li> </ul> </li> <li>Weather conditions <ul> <li>Temperature</li> <li>Equipment (M)</li> </ul> </li> </ul>			

injury risk factors

(Bahr and Holme, 2003; van Mechelan, Hlobil and Kemper, 1992)

This division promotes a distinction between how risk factors are targeted by prevention research, i.e. intrinsic factors may be modulated by the individual themselves whereas extrinsic factors may not. However, it may not be enough to allow effective injury prevention (Bahr and Holme, 2003), as age for example, while intrinsic to the athlete is not modifiable. With this in mind injury risk factors should also be considered as to whether they are 'modifiable' (M) or 'non modifiable' (NM) (Bahr and Holme, 2003), which is also illustrated in Table 2.6. This process should then allow for the selection of valid and effective prevention goals (Bahr and Holme, 2003). In addition, it should be noted that modifiable risk factors may sometimes only be modulated to a certain extent. For example, history of injury may not be modifiable, but standard of treatment and rehabilitation after injury certainly can be modified. Also, playing in poor conditions may be modifiable but only if conditions become so poor as to pose an unacceptable risk (i.e. a frozen pitch vs. cold temperatures). Finally, contact and collision in sport may be modified by wearing protective equipment, or by rule changes to control impact (i.e. scrummaging in rugby union) but may not be entirely controlled because the essence of the sport would be lost. For the current project these distinctions meant that injuries which were not caused by contact would be more attractive for preventative research because the sport of football inherently involves contact between players in terms of tackling, being tackled, and contact with the ball. Any change to this would be in the hands of the governing bodies of the game rather than at club or clinical level meaning that any preventative strategies would be likely to be ineffective.

With this in mind, the earlier summary suggested that in English youth football ankle ligament injuries, as well as muscular strain injuries to the thigh (particularly the hamstrings), were highly and equally prevalent. Therefore following the sequence outlined by van Mechalen, Hlobil and Kemper (1992), an examination of the aetiology of these injuries was undertaken. This suggested that ankle ligament injuries in football commonly occur as a result of external contact, particularly player to player impact onto the medial side of the foot resulting in forced inversion of the ankle and excessive loading of the lateral ligament complex (Andersen et al., 2004). As an extrinsic, non modifiable mechanism this may be difficult to control via preventative strategies. In contrast, a plethora of research (Chumanov et al., 2012; Orchard, 2012; Chumanov, Heiderscheit and Thelen, 2011; Chumanov, Heiderscheit and Thelen, 2007; Heiderscheit et al., 2005; Thelen et al., 2005) has suggested that muscle strains, particularly the hamstrings, are injured via non-contact mechanisms, specifically during sprinting at the late swing phase/early ground contact phase as a result of overload to the muscle tissue at a time of 'active lengthening'. This injury mechanism could be considered intrinsic and therefore under the control of the athlete which may suggest that strategies aimed at risk attenuation could be effective.

## 2.5.1. Risk factors for muscle strain injury

This section specifically considered intrinsic risk factors for muscle strain injury though particular focus was given to the hamstring muscle group. Previous injury was included as a risk factor because although this may not be modifiable it has been suggested that incomplete or poor rehabilitation may be a causation factor for hamstring strains (Crosier, 2004; Orchard et al., 1997) which may be modifiable. Injury risk in youth football may link to the particular patterns of muscular strength and performance which were identified earlier in the review through links to strength deficits, imbalance and asymmetry (Fousekis, Tsepis and Vagenas, 2010). Youth footballers may be at specific risk due to the concept of leg dominance for kicking and cutting skills (Leatt, Shepard and Plyley, 1987). Thus, it may be that the consistent asymmetrical demand of the sport, as illustrated in Figure 2.5 (pp 53) would not only result in particular patterns of muscular strength and performance in youth footballers, but also asymmetrical dom:ndom patterns. To date, this effect remains unproven, particularly in a youth population. However, the concept has been illustrated by the theoretical model of Fousekis, Tsepis and Vagenas (2010), and may be applied to more than one risk factor.



Figure 2.5. Theoretical model of the interaction between muscular strength and performance asymmetry, injury risk and performance in football

Figure 2.5 highlights one theoretical link between the earlier sections of the literature review and injury in youth football, however it should also be noted that sports injuries of any type are almost certainly multi-factorial in nature (van Mechelan, Hlobil, and Kemper, 1992). This means that the muscular strength and performance of youth footballers may only partly contribute to injury risk and that the following discussion of other factors is of prime importance. Unfortunately, there was very little literature directed at injury risk factors for youth football, therefore the studies presented in Table 2.7 (pp 54) generally considered an adult football population (though other populations and methodologies were included where appropriate). It should also be noted throughout, as outlined earlier, that youth footballers have incomplete muscular strength and performance development which could lead to altered load absorption characteristics during football activity (Price et al., 2004).

Studies were only included in Table 2.7 if they took an experimental approach to risk factor identification. This approach was implemented as much of the research to date has focused solely

upon theoretical risk evaluation (Petersen and Holmlich, 2005), which does not equate to a high level of evidence on which to base subsequent intervention strategies.

Author (date)	Methodology approach:	Muscles	Risk factor/s identified
	design, sample (n)	concerned	
Fousekis et al.	Prospective; Adult	Hamstrings	Poor hamstring eccentric strength asymmetry, leg
(2011)	footballers (n=100)	and	length discrepancy (hamstrings) Poor eccentric
		Quadriceps	quadriceps strength, asymmetric flexibility,
			increased body mass (quads)
Venturelli et al.	Prospective; Youth	Thigh strains	Previous Injury, Increased Stature (height)
(2011)	footballers (n=84)		
Engebretsen et	Prospective; Adult	Hamstring	Previous Injury
al. (2010)	footballers (n= 508)	Strains	
Lehance et al.	Retrospective; Youth	Lower limb	Previous injury resulting in muscular imbalance
(2009)	footballers (n=57)		
Crosier et al.	Prospective; Adult	Hamstrings	Hamstrings: Quadriceps imbalance
(2008)	footballers (n=436)		
Bradley, Portas	Retrospective; Adult	Lower Limb	Poor Flexibility
and Barnes	professional footballers		Previous Injury
(2005)	(n=36)		
Brockett,	Retrospective; Adult athletes	Hamstrings	Previous injury resulting in altered AoPT
Morgan and	(n=9)		
Proske (2004)			
Leetun et al.	Prospective; Adult basketball	Lower limb	Poor core stability (specifically hip strength)
(2004)	and track athletes (n=60)		
Bennell et al.	Prospective; Adult Australian	Hamstrings	Previous Injury
(1998)	Rules footballers (n=102)		
Orchard et al.	Prospective; Adult Australian	Hamstrings	Poor Hamstring strength, H:Q imbalance, dom:nom
(1997)	Rules footballers (n=37)		leg asymmetry for the hamstrings
Mair et al.	In Vitro; Fatigue protocol	Extensor	Fatigue
(1996)	and load absorption analysis	digitorum	
		longus	
Yamamoto	Prospective; Adult Athletes	Hamstrings	Poor Hamstring strength, H:Q imbalance
(1993)	(n=64)		

Table 2.7. Evidence based risk factors for muscle strain injury

Table 2.7 suggests that a number of factors may be considered intrinsic risk factors for muscle strain injury. The most commonly cited was previous injury, and this was also the only finding which was specific to a youth football population (Venturelli et al., 2011; Lehance et al., 2009). This increase in risk for injury may be caused by structural healing adaptations to the previously injured tissue including: poor or incomplete immobilisation or remobilisation of the injured tissue,

altered biomechanical loading, or decreased load capability and altered neurodynamic function (Crosier et al., 2008). These factors should be minimised and annulled by appropriate rehabilitation and reconditioning, but many athletes return to play or activity too soon as a result of pressure from external sources or frustration (Crosier et al., 2008) possibly leading to the high re-injury rate noted in the studies above. From a prevention point of view it is clearly a modifiable factor for youth footballers to receive appropriate rehabilitation from injury, however this approach may not prevent those 'first time' injuries which may also damage a players development time and progression.

Another commonly cited factor was strength deficits, muscular imbalance and asymmetry (Fousekis et al., 2011, Crosier et al., 2008; Orchard et al., 1997; Yamamoto, 1993). However, Bennell et al. (1998) denied the existence of muscle imbalance of any sort as a risk factor in their sample. Strength deficits and muscular imbalance link appropriately to the injury mechanism for acute hamstring strains which has been described by numerous authors. Chumanov et al. (2012), Chumanov, Heiderscheit and Thelen (2011), Chumanov, Heiderscheit and Thelen (2007), Heiderscheit et al. (2005), Thelen et al. (2005) described the conditions leading to hamstring strain as a lack of active lengthening force absorption in the late swing/early foot contact phases of running/sprinting gait. Biomechanically this means that the hamstring muscle is in 'outer' functional range as the hip is somewhat flexed while the knee joint is becoming extended. This evidence links appropriately to the research of Brockett, Morgan and Proske (2004) because they suggested that previously injured hamstrings displayed a more 'inner range' (less hip flexion and more knee flexion) position of peak torque and thus, if individuals were to lack strength/force absorption in outer range they may be more likely to suffer injury. This factor may be particularly interesting for youth footballers since it is possible that the physiological processes of the long bones and skeleton during growth could also alter AOPT by interacting with the biomechanical lever over the joints. A further reason for interest in this variable is that strength deficits, imbalances and AoPT may be successfully modifiable through exercise interventions in adults (Brockett, Morgan and Proske, 2004 and 2001; Crosier et al., 2008) but have not yet been trialled in youth footballers.

The other factors in Table 2.7 (pp 54) were: poor flexibility, poor core stability, and the presence of physiological fatigue. Flexibility of the muscles has been linked theoretically by many researchers (Bradley, Portas and Barnes, 2005; Orchard, 2004; Rolls and George, 2004; Ekstrand and Gillquist, 1982) to subsequent muscle strain injury. However there is little empirical evidence to back this claim (Bradley, Portas and Barnes, 2005; Crosier et al., 2008) and researchers have also found no effect on injury incidence after flexibility based exercise intervention (Pope et al., 2000). In addition, there may be some confounding overlap (as with many factors) between the

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presence of decreased range of motion (ROM) as a result of previous injury (Crosier et al., 2008). This was shown by Bradley, Portas and Barnes (2005) who found that their sample of adult professional footballers who had suffered recent muscular strain injury did indeed have decreased joint ROM at the hip, ankle and knee when compared to a reference group. In contrast, Rolls and George (2004) who investigated 111 elite youth footballers could find no such relationship, nor any predictive capability of ROM as a 'risk factor' which was in agreement with Ekstrand and Gillquist (1982). Overall, these findings may suggest that in youth football ROM measurement may not be a useful predictor or correlate with muscle strain injury, even though older age may have a relationship with both decreased ROM and injury.

The relationship of core stability to injury has been highly controversial. Leetun et al. (2004) established that in their sample of adult basketballers and athletes, those who showed less strength in hip adduction and lateral rotation (termed as measures of core stability by the authors) suffered significantly more injuries throughout the subsequent season than those who did not. In contrast, Wallden and Walters (2005) were not able to prove any significant relationship between lumbo-pelvic strength and hamstring injury in their population of adult elite footballers, despite reporting a trend in their findings. The relationship between 'core stability' and 'lumbo-pelvic function' may be explained by considering the functional anatomy of the hamstring muscle group (Figure 1.2a, pp 6). In contrast to many other muscles, the hamstrings are bi-articular which may increase susceptibility to injury (Norris, 2000). Therefore by training the lumbo-pelvic musculature the bi-articular load on the hamstrings could be reduced through lessening their role as a hip extensor. This argument would lead to a protective effect for the hamstrings through a reduction in the active tension in the muscle during gait, however this has not been proven to date. Nonetheless the argument remains of interest, especially for youth footballers who may be still developing kinetic chain motor patterns for sporting action (Wein, 2001) and as such may be ideal candidates for preventative strategies.

Fatigue appears to be a relevant risk factor for muscular strain injury in footballers. The study by Price et al. (2004) suggested that more injuries in youth football occurred toward the end of halves of play. Mair et al. (1996) gives a credible reason for this occurrence by stating that in vitro muscular fatigue lead to decreased active tension. Furthermore, Pinniger et al. (2000) reported a negative effect of prolonged exercise on the hamstrings during the 'late swing' phase of gait. This hamstrings showed increased EMG activity over a longer period during fatigued conditions which was coupled with decreased knee extension range, this was argued to be protective by the authors. Unfortunately, no research has been completed in a youth football population on this topic and it may not be considered ethical to test young participants to exhaustion and fatigue because of the possible discomfort (De Ste Croix, 2007). Youth football games are already

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structured to meet the demands of the youngest youth footballers who may suffer from an earlier onset of fatigue by having the length of halves and games restricted. Thus from an injury prevention perspective, this 'risk factor' may not be wholly modifiable by clinical intervention. Differing rates of growth and maturation during adolescence may mean that fatigue onset may be more individual, at least until the oldest age groups of youth football where 90 minutes games are always played, and the biomechanical and physiological demands begin to plateau. This plateau of demands may allow for intervention strategies to be accurately conceived, however the interaction remains somewhat complex.

Muscular strength imbalance, deficit, and AoPT may be the risk factors of greatest interest for a youth football population. This links well with the previous discussion regarding the nature of youth football training to cause particular patterns of muscular strength and performance development. Poor flexibility does not appear to be a valid 'risk factor' for muscular strain injury in youth while the effects of fatigue and the role of the core stabilisers lack empirical evidence to back up their relationship with injury, but remain of interest due to compelling clinical theory. No studies to date have considered leg to leg asymmetry and injury for this population and therefore inclusion of this variable would be a novel aspect of the current project.

#### 2.5.2. Efficacy of injury prevention strategies

There have been many documented attempts to introduce preventative intervention strategies. Risk factors which have been targeted are: strength imbalance, deficit, asymmetry and AoPT. The main research falls into two schools of thought. Firstly, there have been a number of studies which have targeted the common injuries (including muscular strains) sustained in the sport of football (Brito et al., 2010; Kilding, Tunstall and Kuzmic, 2008; Steffen et al., 2008a and b). These studies have used multiple exercises and an encompassing, rather than a specific approach to injury prevention. Secondly, those who have trialled intervention programmes which target particular muscles, or muscular groups. The majority of this type of research has focused on the hamstrings (Petersen et al., 2010a; Arnason et al., 2007; Askling, Karlsson and Thorstensson, 2003).

There was a paucity of research which concerned male youth footballers because many previous authors have used female participants (Steffen et al., 2008a and b). Despite this, FIFA have claimed success for their '11' and '11+' warm-up exercise regimens for injury prevention in football (Junge et al., 2002) which was developed by their medical research centre (F-MARC). The F-MARC'11' (F11) focuses on core stabilisation, eccentric training, proprioceptive training, dynamic stabilisation and plyometric training, but contains no progression (Kilding, Tunstall and Kuzmic, 2008). It is performed as a warm-up activity and also promotes 'fair play'. One of the few

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studies to report the effects of the F11 programme on functional performance measures, Kilding, Tunstall and Kuzmic (2008) used a cohort whose mean age was  $10.4 \pm 1.4$  years and did not include any isokinetic evaluation, nor any direct analysis of injury occurrence. Due to the age of the participants the nordic lower (eccentric hamstring strengthening exercise) was omitted from the exercise regimen as safety concerns regarding amount of repetitions required (five) were noted by the authors. Safety concerns are commonly cited as reasons why children should not complete resistance exercise, however Tolfrey (2008) argues that upon closer inspection of the literature the fear of increased injury to children who train using resistance is unfounded, and that injury in most cases may attributed to a lack of supervision and risk control by adults (Tolfrey, 2008).

Kilding, Tunstall and Kuzmic (2008) reported that six weeks of participation in the F11 resulted in significantly improved vertical jump power (6.0%), three step jump for co-ordination (3.4%) and 20 metre sprint time (2.0%) for the intervention group compared to a control. However, they also commented that some participants became 'bored' by the exercise regimen which affected the suitability of the programme. In contrast, Brito et al. (2010) examined the isokinetic strength effects of the 'F-MARC 11+' (the 11 with exercise progression included, F11+). They used a cohort of young adult footballers (n=20) and found that as a result of the programme the PT of CH and CQ significantly improved, as did muscle balance (measured by a dynamic control ratio and CHQ). In similarity to Kilding, Tunstall and Kuzmic (2008), Brito et al. (2010) did not measure the effect of the programme on injury incidence and so the scope of their conclusions was also limited. In addition Brito et al. (2010) did not utilise a control group, this means that while their results may be perceived as encouraging for injury risk attenuation, the effects reported may not be solely attributable to the F11+.

Only Junge et al. (2002) investigated the effect of the F11 exercise on injury incidence. They reported that the teams who had participated in the educational programme (including coach education on fair play) had a significantly reduced total injury rate, and significantly reduced non contact, overuse, training, mild severity and groin injuries. However, the effect of the F11 on specific types of injury was not clear, and due to the breadth of the programme it may be considered exceptionally difficult to elaborate on the reasons for the observed decrease.

In summary, there is limited evidence that the F11 and F11+ programmes decrease injury, especially since the positive results of the Junge et al. (2002) study may be countered by the negative results of studies undertaken in female youth footballers (Steffen et al., 2008a and b). However, there is evidence to suggest that muscular strength and performance may be improved by the programmes of exercise, although the mechanisms through which this and injury prevention remain unclear due to the lack of research on the topic.

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With regard to the second school of thought, injury prevention of the thigh musculature, it may be important to note that many of the studies presented below did not directly measure the effect of their intervention on injury incidence post intervention. Most studies simply reported the effect of the intervention upon the identified risk factor, and while this is not an ideal approach it may be considered that research of this nature is somewhat more feasible to perform. This is perhaps most evident in the case of elite sport, where it is difficult to enter individuals into randomised controlled trials (Arnason et al., 2007). Furthermore, studies which measure the effect of an intervention on injury need to last for a minimum of two seasons so that an accurate comparison could be made, or have a clearly defined control group, and have the additional need for clear and accurate injury monitoring (Fuller et al., 2006). This may mean that this level of research was impractical for some authors.

Askling, Karlsson and Thorstensson (2003) noted the effect of an exercise intervention on the prevalence of hamstring injuries. This study was specific to football using 30 elite adult male participants (control, n=15; intervention, n=15) and measured isokinetic strength and muscle performance of the hamstrings and quadriceps, as well as injury prevalence pre and post an exercise intervention which targeted eccentric loading of the hamstrings. The training group significantly increased CH and EH PT in comparison to the control group (~17% stronger), and suffered significantly less hamstring injuries over the course of the playing season (intervention= 3/15; control= 10/15). The authors argued that the decrease in injuries was due to attenuation of decreased hamstring strength as a risk factor. They also acknowledged that the specific dose/response interaction between strength performance increase and injury could not be determined. This may be especially relevant due to the results of previously discussed literature (Bennell et al., 1998; Orchard et al., 1997; Table 2.7 pp 54) who reported directly conflicting results regarding the presence of this relationship.

Petersen et al. (2010a), Arnason et al. (2007) and Gabbe, Branson and Bennell (2006) showed agreement with Askling, Karlsson and Thorstensson (2003). These authors performed studies in elite adult football and Australian football respectively using large scale designs. Petersen et al. (2010a) and Arnason et al. (2007) both used a team based approach to measure efficacy of interventions containing eccentric strength training of the hamstrings. Petersen et al. (2010a) had a control group of 481 players and an intervention group of 461 players (whole teams present in each group) who completed 10 weeks of the nordic lower exercise. In contrast, Arnason et al. (2007) prescribed two intervention strategies to 24 teams of Scandinavian footballers. Both interventions included warm-up stretches and flexibility, but only one included eccentric training of the hamstrings. A strength of this design was that there was limited potential for contamination as whole teams were assigned to intervention (n=11 teams) or control (n=13

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teams). The results of both studies were encouraging with Petersen et al. (2010a) recording hamstring injury incidence in the intervention group to be 3.26 times lower than the control. Similarly, Arnason et al. (2007) showed a 2.81 times lower incidence of hamstring strains post intervention for the teams that undertook the programme including eccentric hamstring training. However, for both studies specific muscular strength and performance pre and post exercise intervention was not recorded, meaning that actual strength increases could not be quantified and therefore the reason for the recorded injury incidence decrease could not be adequately elucidated.

In other sports, Tyler et al. (2002) found that a specific adductor muscle strength training programme significantly decreased the incidence of groin strain injury in professional ice hockey players, and Gabbe, Branson and Bennell (2006) concluded that eccentric exercise for the hamstrings may decrease injury incidence in Australian football. Unfortunately, the Gabbe, Branson and Bennell (2006) study was hampered by low adherence and compliance with the intervention regimen set by the authors. Neither Petersen et al. (2010a), Arnason et al. (2007) nor Askling, Karlsson and Thorstensson (2003) made reference to this problem as part of their studies, but many authors who have attempted to test the effect of injury prevention strategies have cited similar methodological issues (Emery and Meeuwisse, 2010; Engebretsen et al., 2008; Soligard et al., 2008). This is important because it confirms that injury prevention strategies may be most effective in those who comply with the exercise regimen (Soligard et al., 2010). Furthermore, this may have implications for the current project as any injury prevention strategy undertaken should also be judged by compliance as well as effectiveness.

Other studies have considered the effect of eccentric exercise on muscular strength and performance, and have linked their findings to injury prevention through modulation of predisposing risk factors. These types of studies may also go some way to explaining the rationale and physiological effects/changes which may be responsible for the decreased injury rates seen post intervention in the aforementioned studies. Again, many of the studies focus solely on the hamstring musculature. The first of these factors is muscular strength as measured by isokinetic PT and muscle balance as measured by an H:Q ratio (Mjolsnes et al., 2004). The authors found that a 10 week programme of nordic lowers significantly increased eccentric hamstring strength by 11% and improved FHQ (0.89 pre, 0.98 post). This type of finding was also echoed by Kaminski, Wabberson and Murphy, (1998) who reported a 29% increase in eccentric hamstring strength after only six weeks in their untrained participants, compared to a 19% increase in concentric strength. These findings suggest contraction mode specific effects for intervention exercise.

EMG studies have shown that the hamstrings are most active at the end of the swing phase and early stance phase of sprinting gait (Simonsen, Thomsen, and Klausen, 1985). At this time they

work to control the knee joint with an eccentric contraction which is where injury is postulated to occur (Chumanov et al., 2012; Orchard, 2012). Animal studies have suggested that forceful eccentric contractions may cause muscle damage (Lieber and Friden, 1993). Thus, if the eccentric strength of the hamstrings may be increased by mode specific eccentric exercise muscle damage may be prevented. Of further interest from this perspective is hamstring AoPT. This factor has been reported to alter as a result of eccentric exercise of the hamstrings, both immediately (Brockett, Morgan and Proske, 2001) and as a result of a programme of eccentric exercise using nordic lowers (Clark et al., 2005). Therefore, if eccentric training of the hamstrings may result in increased strength in the 'risk' range of late swing (which includes knee extension (Chumanov et al. 2012)) muscle damage and particularly strains might be prevented.

The two mechanisms for risk modulation outlined above may go some way to explaining the findings of those authors who reported decreases in injury prevalence as a result of eccentric hamstring training. Unfortunately no studies to date have considered these factors in one single study and so the link and mechanism can only be suggested at this time. Furthermore, one must accept that injury aetiology must be considered as multi-faceted meaning that modulation of one risk factor (PT, AoPT, muscle balance or asymmetry) may not be enough to prevent all injuries for all participants. In addition, confounding information exists because Clark et al. (2005) reported interesting findings related to asymmetry. They discovered that the difference between the AoPT of the dom and ndom legs was actually larger after an exercise intervention. It was therefore postulated that bilateral exercise intervention alone may indeed worsen asymmetry because the dom leg would adapt more effectively than the ndom leg (Clark et al., 2005). Unfortunately, this finding remains unconfirmed to date.

In summary, there appears to be good evidence for the inclusion of eccentric hamstring training to reduce the risk of hamstring injuries, a view which was shared by Hibbert et al. (2008) in their review on the subject. Further studies are required for other muscle groups, and randomised controlled trials and studies which combine muscular adaptations; asymmetry monitoring and injury incidence recording have not yet been published. This may be of importance for youth footballers as the combination of growth, development and football training may appear to predispose to muscle imbalance, asymmetry, strength deficit and possibly injury. Therefore it is incumbent upon researchers to consider this group.

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#### 2.6. Conclusions from the review of literature

This review of literature highlighted that isokinetic evaluation at 60°/s is a valid and reliable method for investigation of the particular patterns of muscular strength and performance across chronological and biological ageing in youth football. Comparison between young male non specific and football populations revealed that increased CQ may be expected along with a possibility for relatively weaker CH even when normalising for BW, using the crude but valid grouping method of chronological age groups. There was no evidence to suggest that CHQ and FHQ were modulated by chronological or biological ageing, although some evidence did exist for adult payers which suggested that dom:ndom asymmetry might be expected with a short professional training history as youth players would be bound to have.

It was also clear from the review that English youth footballers enter a distinct and performance driven environment when they are registered with elite academies and centres of excellence. Unfortunately, no research yet exists which can definitively answer the question of whether the muscular strength and performance of youth footballers is inherent or as a result of training. Nonetheless, there does appear to be a considerable injury problem in youth football which is concerning due to the possible effect on future career and on health, though there is little research which can substantiate or quantify this effect. Injury in youth football did appear to have relationships with chronological and biological ageing, but the current evidence was lacking in specificity and power. No studies to date have completed an analysis linking muscular strength and performance throughout ageing with this factor, particularly with reference to the English system which suggests a considerable dearth of evidence based knowledge for those who work with this population.

Hamstring muscle strains were a common injury in elite male youth football. This conclusion linked appropriately with the observed patterns of strength and muscular performance noted earlier in the review, particularly the lack of data available regarding injury risk factors such as hamstring strength, balance and asymmetry throughout ageing. There was considerable evidence to suggest that a programme of eccentric exercise may be beneficial in reversing injury risk factors relevant to hamstring strains, though no research to date has considered this intervention strategy in male youth footballers.

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#### 2.7. Aims and objectives of the current project

The current project aimed to increase understanding of aetiology and risk of injury in youth football. The review of literature highlighted muscular strength and performance characteristics of the players of the youth game and how they might differ from youths who participate in other sports, and non sport-specific youths. Particular patterns of injury and possibilities for prevention through risk factor attenuation were identified. This highlighted the thigh musculature (specifically the hamstrings) for intervention through eccentric exercise with the aim of increasing strength, decreasing imbalance and asymmetry, and moving AoPT toward outer range.

The first objective of the current project was to investigate the specific pattern of isokinetic muscular strength (PTBW) and performance (H:Q, dom:ndom asymmetry and AoPT) for elite male English youth footballers. The reasons were threefold: Firstly, there was a lack of isokinetic muscular strength and performance evaluation literature for a wide age range of youth/adolescence population because many studies have simply focused upon PT alone. Secondly, there was little to no data on these factors for English youth footballers, and thirdly English youth footballers appeared to suffer a slightly different injury pattern to other nations, and it was possible that any strength deficit, altered AoPT, leg to leg asymmetry or muscular imbalance as a result of the English system and training may be implicated in the rationale to explain this. As a result of this literature review, it was expected that English youth footballers would display a pattern of increasing isokinetic hamstrings and quadriceps strength leading to muscular imbalance (H:Q) in the older chronological age groups, while the opposite was expected to the complicated interaction between chronological ageing and biological ageing. It was also expected that increasing biological age would result in similar findings to chronological ageing.

The second objective was to determine the pattern of muscular strength and performance factors across a competitive season. This was achieved by tracking the youth/adolescent participants across the competitive football season and completing longitudinal evaluation of the muscular strength and performance of the hamstrings and quadriceps. The rationale was again threefold: Firstly, to determine whether the pattern of muscular strength and performance development was a stable trait in the population of interest and was therefore a reliable starting point from which to derive further research questions regarding relationships with preventable muscular injury. Secondly, to investigate whether seasonal variation in muscular strength and performance may highlight periods of the competitive season when preventable muscular injury risk may be heightened, and thirdly, to analyse the seasonal variation in light of the temporal injury prevalence information given by Price et al. (2004) which highlighted immediately after breaks as times of increased injury incidence. Given the findings of review of literature it was expected that

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patterns of muscular strength and performance development would be stable over the course of the season and were unlikely to show a relationship with the periods of increased injury incidence.

The third objective was to understand the problem of injury in youth football and its relationship with muscular strength and performance in the population of interest. The rationale for this was twofold: firstly to compare the problem of injury in the participants of the project to that illustrated by previous literature, and secondly to follow the sequence of van Mechelan, Hlobil and Kemper (1992) by understanding the possible risk factors and causation for the common injuries in youth football, and their interaction with muscular strength and performance. It was expected that previous muscular injury would show a negative relationship with isokinetic muscular strength and performance and that both prospectively and retrospectively there would be strength deficits and imbalances present in the 'injury' groups.

The fourth and final objective was to ascertain whether the highlighted injury risk factors for muscle strain injury could be modulated by an exercise intervention compiled from the programmes shown to be effective by previous research. This was undertaken in a youth/adolescent English male population which was a novel aspect of the project, and included analysis of all the aforementioned factors such as PTBW, AoPT, H:Q, and dom:ndom. It was expected that as a result of the exercise intervention that the injury risk factors would be positively modulated, however it was beyond the scope of the study to evaluate the actual impact on injury incidence.

#### Chapter Three: General methodology

#### 3.1. Participants

The participants for this project were the full playing rosters of the U12 to U18 age groups from the centre of excellence (CoE) training facilities of two championship football teams. Inclusion criteria required that all participants were registered to play in U12-18 teams in the season 2007/2008, and to be free from injury at the time of isokinetic evaluation. For Chapters Four to Six, all participants were invited to attend the laboratory on three occasions throughout one competitive season for data collection (2007/2008). Injury and unavailability over the course of the season meant that the participant numbers were different for each of these studies as outlined in the detailed methodology for each experimental chapter. During the 2008/2009 season no evaluation was undertaken. The final Chapter (Seven) targeted the U18 age group for a preventative exercise intervention in July-September of the 2009/2010 season. For this chapter participants were only recruited from one CoE.

The current project was approved by the departmental and University ethical procedures committee and followed the principles outlined in the Declaration of Helsinki. Club and participant information was anonymised, kept strictly confidential and results were kept on a password encrypted computer. Parental consent was gained from participants who were under 16 at the time of testing. Consent was also gathered to pass any relevant results back to the club and the coach of the particular age group. Participants were made aware of the rigors of involvement using information sheets (Appendices A and F) and informed consent forms (Appendix B); this ensured that participants understood they could withdraw at any time. Inclusion suitability was investigated using a pre-exercise medical questionnaire (Appendix C), using input from club medical personnel who 'passed' each participant 'fit' to complete each study. Throughout all testing researchers were also available to answer any parental or participant questions. All researchers conducting this study were approved by the Criminal Records Bureau (CRB) enhanced disclosure form prior to testing.

#### **3.2.** General procedures

The design of the project encompassed one competitive season of data collection (2007/2008) with staggered data collection periods as the U18 age group began their season earlier (August) than the U12-16 age groups (September). Chapter Four utilised data from the start of season (SS), whereas Chapters Five and Six utilised data from three testing sessions over the course of that season, including SS, mid-season (January; MS) and end of season (April; ES). Chapter Seven comprised of the intervention which was completed prior to and at the beginning of the

2009/2010 season. Data collection took place when the participants would normally have undergone football training. For the U12 – U16 age groups this entailed evening testing, however, the U18 group testing took place in the afternoon. This design was implemented to increase the ecological validity of the findings for the specific age groups.

#### *3.2.1. Determination of age*

Chronological age of the participants was calculated using the reference point of birth-date (day, month, year) to the date (day, month, year) at which isokinetic evaluation occurred. Chronological age was measured in years and months throughout the study. Chronological age groups were organised according to the scholarly academic calendar where the 1<sup>st</sup> day of September constitutes the reference points between groups, this was to ensure the validity, and to maintain comparability across youth football training structure which is organised similarly. In later chapters, chronological age categories were also used, these categories were organised by grouping more than one single year chronological age group.

Biological age was determined through the self reporting of secondary sex characteristics in comparison to peer group at SS only, and was standardised using the pubertal development scale (PDS; Petersen et al., 1988; Appendix D). This method was chosen over x ray analysis of skeletal age, or direct visual estimation of secondary sex characteristics to protect subjects from exposure to radiation and embarrassment. Petersen et al. (1988) reported good repeatability (alpha coefficients of 0.68–0.83) for the PDS scale using a repeated measures approach and, despite its limited inference, a moderate to high correlation with direct measures of pubertal development as measured by Tanner staging (alpha coefficients of 0.61 – 0.67). Answers to the PDS questionnaire were collated to provide a score for pubertal development based on Tanner staging, ranging from one to five according to the procedures set out by Petersen et al. (1988). Participants of similar PDS status were then 'grouped'. Throughout the study, participants completed the PDS in isolation after an individual explanation of the questionnaire by researchers.

## 3.3. Season long data collection procedural overview

At SS, MS and ES all participants completed isokinetic evaluation of the thigh musculature using a Biodex, system three, isokinetic dynamometer (Biodex Medical, NY, USA). Age groups were staggered so that the age groups from the two teams were tested together in either week one, two, three or four of the month. All testing sessions followed at least 24 hours rest from club organized football activity. The order of testing remained consistent throughout the season. Over the course of the season participants also completed muscle strain injury logs (Appendix E) when they attended the University.

# 3.3.1 Isokinetic evaluation procedure

Adjustments were made individually according to manufacturer guidelines (Biodex system 3), including: 1) chair positioning, adjustment in the vertical and sagittal planes to ensure that the lateral epicondyle of the femur was aligned with the central axis of the dynamometer (performed in knee flexed, relaxed position with no straps), 2) strap and support positioning, waist, thigh and upper body straps, which aimed to control contributory effort from untested musculature and standardise body position at 90° hip flexion, 3) eccentric torque resistance level, this was set by chronological playing age group after the familiarisation sessions, with the younger participants needing to initially apply less torque to the dynamometer to achieve the eccentric contraction, and 4) calibration of the dynamometer to the participant. This fourth level of adjustment was made via measurement and input of subject specific range of motion for full active knee flexion (start position for all tests) and extension using the reference of 90° (equals vertical), input of height and weight, and a measure of the whole leg weight in foot pounds (Ft-lbs) performed in a knee extended position, just off full knee extension (with relaxed thigh musculature) to allow for accurate gravity correction, and AoPT monitoring. After gravity correction and leg dominance (leg chosen to kick with) were recorded, participants performed three minutes warm up on a cycle ergometer (Monark 824E, Monark Exercise AB, Varberg, Sweden; resistance 50-60W). Isokinetic evaluation consisted of two sub-maximal repetitions before each set of five maximal repetitions for each muscle and type of contraction. Bilateral measurement conditions included CQ, CH and EH PT, averaged (Biodex system 3 software) from repetitions two, three and four which aimed to reduce any effects of inexperience and fatigue common in younger participants (De Ste Croix, Deighan and Armstrong, 2003). The isokinetic speed used was 60°/s because this was an appropriate speed to give reliable results in adolescents (Iga et al., 2006; De Ste Croix, Deighan and Armstrong, 2003; Kellis et al., 1999) and provides a good opportunity to investigate AoPT (Kannus and Beynnon, 1993; Brockett, Morgan and Proske, 2001). In addition, 60°/s was used by many of the previous studies (Table 2.2, pp 29) which have considered isokinetic strength in youth footballers allowing for maximum comparability with the existing literature. Condition order was CQ and CH followed by EH; however, the order of assessment of the dom and ndom limb was counterbalanced. Specifically, odd numbered participants completed dom CQ, dom CH, ndom CQ, CH followed by ndom EH, dom EH, with the opposite true for even numbered participants. Participants were permitted two minutes rest between leg to leg and concentric to eccentric testing in an attempt to control for fatigue (De Ste Croix, Deighan and Armstrong, 2003). Participants were also given repeated instructions to "kick out" and "pull in" to elicit a maximal

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effort throughout range during all tests. This additional verbal queue was provided to try and control the standard of performance throughout the whole range of motion.

The sensitivity of this procedure for all of the isokinetic dependant variables (PT CQ, CH and EH, PTBW CQ, CH and EH, CHQ, FHQ, CQ:CQ, CH:CH, and EH:EH) is presented in Tables 3.1 3.2 and 3.3, These tables were used to clarify the meaningfulness of changes to dependant variables throughout the subsequent chapters. The analysis was performed by considering a random sample of 12 participants, from all age groups and both centres of excellence, and taking the single highest and lowest measurements recorded for repetitions two, three and four of the testing. Following this, the change between the maximum and minimum values was calculated (maximum minus minimum) for each participant; this was then averaged (change divided by 12) and used throughout the current project to highlight internal variability of the sample. Only the range is presented because the absolute measurements (min/max) may be affected by age and may have been misleading.

Dependant Variable (unit of measurement)	Leg	Range (min to max of reps 2 - 4, averaged across random sample (n=12))
PT CQ (Nm)	dom	5.69
	ndom	10.10
PT CH (Nm)	dom	7.80
	ndom	8.59
PT EH (Nm)	dom	12.13
	ndom	13.68
AoPT CQ (°)	dom	8.50
	ndom	8.83
AoPT CH (°)	dom	12.25
	ndom	19.42
AoPT EH (°)	dom	13.00
	ndom	17.08

Table 3.2 Variability of relative measures (PTBW and H:Q)

Dependant Variable (unit of measurement/ derivatives)	Leg	Range (min to max of reps 2 - 4, averaged across random sample (n=12))
PTBW CQ (Nm/kg)	dom	0.11
	ndom	0.18
PTBW CH (Nm/kg)	dom	0.14
	ndom	0.16
PTBW EH (Nm/kg)	dom	0.20
	ndom	0.25
CHQ (conH:conQ)	dom	0.09
	ndom	0.11
FHQ (eccH:conQ)	dom	0.15
	ndom	0.22

Dependant Variable (derivatives)	Range (min to max of reps 2 - 4, averaged across random sample (n=12))			
CQ:CQ (dom:ndom)	0.11			
CH:CH (dom:ndom)	0.21			
EH:EH (dom:ndom)	0.14			

# Table 3.3 Variability of relative measures (dom:ndom)

# 3.3.2. Isokinetic familiarisation procedure

Prior to the SS assessment all participants attended the laboratory to collect anthropometric data and then perform a unilateral isokinetic familiarisation protocol for each condition involving fiveseven repetitions. This was conducted primarily to acquaint the adolescent population with the potentially novel sensation of an eccentric contraction (De Ste Croix, Deighan and Armstrong, 2003), as well as offering researchers the opportunity explain the testing procedure individually and ensure that all participants were accustomed to the demands of the isokinetic dynamometry.

## 3.4. Intervention procedural overview

The U18 age group were targeted for an intervention exercise programme which aimed to attenuate hamstring injury risk factors, this immediately preceded the 2009/2010 competitive season. Pre and post exercise intervention, the participants completed isokinetic evaluation with a controlled procedure as outlined above. Detailed methodology and procedure is available in Chapter Seven.

## 3.5. Data and statistical analyses

The specifics of the data reduction and statistical analysis performed are available throughout the experimental Chapters (Four - Seven). However, for clarity Microsoft Excel (2007 version, Microsoft Inc, USA) and Statistical Package for the Social Sciences (SPSS) software, version 16 (IL, USA) was used throughout the project. Appropriate tests to consider differences between participant demographics (for example, height, weight, centre of excellent played for) were performed for each chapter, and were reported alongside the participant demographic data tables. Significance was always accepted at the  $p \le 0.05$  level.

Chapter Four: Muscular strength and performance in youth footballers: Isokinetic evaluation with reference to chronological and biological age, and leg dominance

### 4.1. Introduction and background

Muscular strength and performance in youth and adolescence is often poorly understood due to the intricate growth and maturational events which are inherent to the population (De Ste Croix, 2007). Participation in sports can also be a confounding factor and this may be of particular note for footballers (Stratton et al., 2004). To date, various authors have attempted to understand muscular strength and performance patterns which are specific to: biological ageing through pubertal development (Hansen et al., 1999; Maffulli, King and Helms, 1994), chronological age (Ellenbecker et al., 2007; Buchanen and Vardaxis, 2003; Gerodimos et al., 2003), football (Kellis et al., 2001; Rochcongar et al., 1988; Leatt, Shephard and Plyley, 1987) and asymmetry through leg dominance (Zakas, 2006; Rahnama et al., 2005; Kramer and Balsor, 1990). However, it remains unclear how these factors interact and combine to affect muscular strength, muscle balance and other muscular performance factors, all of which may be important for both training and injury prevention in young footballers. To this end, isokinetic evaluation is suitable to provide information regarding muscular strength (PT, PTBW) and muscular performance (AoPT, muscle balance (CHQ, FHQ) and dom:ndom asymmetry).

Of the measures above, PT and PTBW have been shown by numerous studies to increase with age (Ellenbecker et al., 2007; Barber-Westin, Noyes and Galloway, 2006; Cometti et al., 2001; Kellis et al., 2001; Chin et al., 1992), but only one of these studies has illustrated this variable with reference to a wide cohort of youth footballers (Kellis et al., 2001). AoPT has been reported for adult populations, but recent interest in the eccentric function of the hamstrings for injury prevention (Brockett, Morgan and Proske, 2004) suggested that this variable may also be of interest in youth footballers. CHQ and FHQ have been reported previously for youth footballers aged 14-18years (Rochcongar et al., 1988; Iga and George, 2005), and 12-18years (Kellis et al., 2001) but no clear relationship to chronological or biological age, or sport has been established. Dom:ndom asymmetry has also received little research attention, despite the common assertion that muscle imbalance and asymmetry are risk factors for injury (Orchard et al., 1997; Yamamoto, 1993; Worrell and Perrin, 1992).

In summary, very little previous research has utilised large cohort, long-term longitudinal, or cross sectional designs to investigate muscular strength and performance throughout youth (De Ste Croix, Deighan and Armstrong, 2003). This has resulted in limited knowledge of the pattern of thigh muscular strength and performance, particularly in English youth football. The present study may be the first to include comparatives of both chronological (yearly playing age group)

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and biological age into a cross sectional study in this population. This approach could lead to a better understanding of the complicated transition period from youth to adulthood while training for football, and may allow specific training, injury prevention and rehabilitation recommendations.

The purpose of this investigation was to illustrate age group and pubertal development muscular strength and performance patterns across chronological and biological ageing in a large cohort of elite male youth footballers. The following research questions were to be answered: 1) what is the muscular strength development pattern for CQ, CH and EH when considering age group, and PDS group, 2) Is there an independent effect for chronological or biological ageing on PT and PTBW of CQ, CH and EH, 3) what is the normal development pattern of AoPT of CQ, CH and EH when considering chronological and biological age, 4) what is the relationship between AoPT and muscular strength in this population, and 5) what is the development pattern of muscular balance and asymmetry when considering chronological and biological and biological ageing.

In response to these research questions, the following hypotheses were derived: 1) PT and PTBW would increase with chronological and biological ageing, 2) There would be no independent effect for either age measure, 3) AoPT would not show a significant relationship with either age measure, 4) There would be no significant relationship between AoPT and muscular strength, and 5) Muscle balance would not show a significant relationship with either age measure, however asymmetry may be expected in the younger participants who would have a shorter training history than the older age groups.

#### 4.2. Methodology

### 4.2.1. Participants

One hundred and fifty seven male elite youth football participants belonging to two CoE operating in the north of England volunteered to participate in the study. Participants gave informed consent (additional parental consent was attained if under 16) and completed a pre-exercise medical questionnaire. None of the participants were suffering from musculoskeletal injury and all were registered to play for the U12-U18 teams. The study was approved by the departmental and University ethical procedures committee and followed the principles outlined in the Declaration of Helsinki.

## 4.2.2. General procedures

The procedure for this study, including isokinetic evaluation, familiarisation and assessment of both ageing variables has been outlined in Chapter Three (pp 65-69).

Participants were removed from further analysis if they did not complete the required repetitions for all conditions on both legs. This led to the exclusion of four participants. One further participant was excluded due to a calibration error with the Biodex dynamometer leaving 152 participants for age group analysis (Table 4.1), and 134 for PDS analysis (Table 4.2). Participants who did not complete the PDS appear in chronological age group data sets only. No significant differences were observed between the two CoE for any of the measured parameters and therefore the all data was pooled.

Chronological age group		Height (cm) $\bar{x} \pm SD$ Weight (kg) $\bar{x} \pm SD$		Age (years) x ± SD	
U12	n= 24	148.1 ± 6.2	40.7 ± 7.8	11.6 ± 0.3	
U13	n=25	157.0 ± 8.6	48.3 ± 9.6	$12.6 \pm 0.3$	
U14	n=27	162.5 ± 9.8*	51.1 ± 10.7*	13.7 ± 0.3	
U15	n=21	174.2 ± 5.8	62.7 ± 8.7	14.7 ± 0.3	
U16	n=26	174.8 ± 6.6#	63.0 ± 6.7#	15.7 ± 0.3	
U18	n=29	178.8 ± 4.5	70.2 ± 6.2	17.1 ± 0.6	
Total	n =152	165.9 ± 12.0~	56 ± 11.1	14.2 ± 2.0	

\*U14 not significantly taller or heavier than U13. #U16 not significantly taller or heavier than U15. U18 not significantly taller than U16. All other between age group comparisons for height and weight significantly different (p<0.05)

Group (Petersen e	et al., 1988)	Height (cm)	Weight (kg)	Age (years)	% Age group
		$\bar{x} \pm SD$	$\bar{x} \pm SD$	$\bar{x} \pm SD$	
PDS1(pre-	n=1	147.0 ±0.0	$41.5 \pm 0.0$	$11.9 \pm 0.0$	U12 – 100%
pubertal)					
PDS2(beginning	n=20	152.1 ± 9.5*	44.2±12.1*	$12.1 \pm 0.9$	U12 – 60%; U13 – 25%; U14 – 10%;
pubertal)					U15 – 5%;
PDS3(mid	n=53	161.1± 10.9*	50.8±10.4*	13.7 ± 1.4	U12 - 13%; U13 - 23%; U14 - 30%;
pubertal)					U15 – 11%; U16 – 21%; U18 – 2%
PDS4(advanced	n=55	176.3 ± 6.3*	65.3 ± 8.1*	15.7 ± 1.4	U13 – 3%; U14 – 12%; U15 – 20%; U16
pubertal)					– 27%; U18 – 38%
PDS5(post	n=5	173.8± 16.3	67.4±16.2	16.0 ± 2.2	U13 – 20%; U16 – 20%; U18 – 60%
pubertal)					
Total	n=134	162.1 ± 12.9	53.8 ± 11.9	13.9 ± 1.9	N/A

#### Table 4.2. Subject demographics by biological age grouping (PDS)

\*PDS groups 2 - 4 significantly different height and weight

### 4.2.4. Statistical analysis

Bilateral PT, PTBW, and associated AoPT for conditions CQ, CH, and EH were recorded along with calculations of FHQ, CHQ and dom:ndom ratio. Statistical analysis was carried out using SPSS version 16 (Chicago, IL. USA). A mixed model ANOVA with SIDAK correction was completed for chronological age group (U12 - 18) x leg (dom, ndom), and biological age group (PDS) x leg (dom, ndom) for PT, PTBW, AoPT, FHQ and CHQ. In addition, a one-way ANOVA with SIDAK correction was completed for was completed for dom:ndom ratios (CQ:CQ, CH:CH, EH:EH). Quantile-quantile (Q-Q) plots were

plotted and reviewed for each variable to justify the use of parametric statistical tests. Q-Q plots suggested acceptable normality of data for each variable because there was no consistent or substantial 'sagging' nor 'rising' away from the line of normal distribution (Field, 2009). If data did not meet the assumptions of homogeneity (Levene's test), the Games-Howell test was applied to determine significant differences and effect sizes. For PDS biological age analysis inferential statistics were only undertaken on groups two-four (n=128) due to low subject numbers in PDS groups one and five (Table 4.2).

In order to establish differences between chronological and biological age grouping an additional mixed model ANOVA was completed for chronological age group (U12-18) x leg (dom, ndom) for the age groups represented within PDS group 3 (Table 4.2). Finally, in order to establish the correlation between PTBW and AoPT, Pearson's correlations were performed for CQ, CH and EH after appropriate outliers were removed. Statistical significance was accepted at p<0.05 and data are presented as mean ( $\bar{x}$ ) ± standard deviation (SD). For clarity, only significant effects were reported.

### 4.3. Results

### 4.3.1. Peak torque and chronological age

There was an effect for PT CQ (F (5, 147) =52.8;  $p \le 0.001$ ), PT CH (F (5, 147) =28.2;  $p \le 0.001$ ), and PT EH (F (5, 147) =33.8;  $p \le 0.001$ ) between age groups. *Post hoc* analysis revealed that for CQ, the U18's had greater PT than all other age groups (U12-14  $p \le 0.001$ ; U15 p = 0.003; U16 p = 0.008). The U16 and U15's had greater PT than U14 and younger ( $p \le 0.001$ ), and the U14's had greater PT than the U12's (p = 0.005; Table 4.3). For CH and EH, the U18's, U16's and U15's had greater PT than U14 and younger ( $p \le 0.013$ ). There were no interactions (age group x dominance) for any of the PT variables, nor was there an effect for dominance.

## 4.3.2. Peak torque and biological age

There was an effect for PT CQ (F (2, 125) =51.3; p≤0.001), PT CH (F (2, 125) =35.2; p≤0.001), and PT EH (F (2, 125) =36.6; p≤0.001) between PDS groups. *Post hoc* analysis revealed that for CQ, CH and EH PDS 4 had greater PT than PDS 2 and 3 (p≤0.001; Table 4.3). There were no interactions (PDS group x dominance) for any of the PT variables nor was there an effect for dominance, thus Table 4.3. illustrates the mean of dom and ndom legs.

	Concentric Quadriceps		Concentric Hamstrings		Eccentric Hamstrings	
Group	PT (Nm) x̄ ± SD	AoPT (°) x̄ ± SD	PT (Nm) x̄ ± SD	AoPT (°) x̄ ± SD	PT (Nm) x̄ ± SD	AoPT (°) x̄ ± SD
U12	80.70 ± 22.75	72.7 ± 8.0	43.20 ± 12.15	57.5 ± 14.6	79.50 ± 20.10	35.6 ± 13.4
U13	93.75 ± 25.00	76.2 ± 11.7	53.15 ± 13.60	62.5 ± 16.3	94.05 ± 18.15	33.8 ± 10.4
U14	109.55 ± 28.50	78.3 ± 9.1	59.30 ± 13.00	57.3 ± 12.8	100.25 ± 23.6	34.7 ± 10.1
U15	151.10 ± 37.80∞	76.3 ± 8.9	80.30 ± 18.75∞	59.7 ± 13.1	135.50 ± 32.35∞	35.4 ± 10.6
U16	152.10 ± 28.35∞	75.9 ± 7.9	89.70 ± 44.75∞	56.2 ± 12.1	140.05 ± 29.95∞	33.6 ± 20.7
U18	182.25 ± 27.75*	76.3 ± 7.3	97.10 ± 18.30~	51.6 ± 9.8 ×	151.00 ± 28.60~	38.7 ± 12.4
PDS2	95.20 ± 23.60	74.8 ± 9.1	50.35 ± 14.25	58.4 ± 13.9	86.85 ± 22.60	34.7 ± 12.4
PDS3	106.90 ± 35.70	76.2 ± 9.0	58.70 ± 17.25	$60.4 \pm 13.9$	103.25 ± 30.80	36.3 ± 15.7
PDS4	162.55 ± 35.75#	76.6 ± 8.8	91.00 ± 36.50#	$53.1 \pm 11.6\alpha$	141.95 ± 31.10#	34.5 ± 13.0

Table 4.3. PT and corresponding AoPT for CQ, CH and EH (mean of dom and ndom legs)

\*U18 greater than all younger (U12-U14: p<0.001, U15: p=0.003, U16: p=0.08). ~U18 greater than U14 and younger (p<0.001). ∞U16 and U15 greater than U14 and younger (p<0.001, except CH U15-U14 p=0.013). #PDS 4 greater than PDS 2 and 3 (p=<0.001). ×U18 more outer range than U13 (p=0.011).αPDS 4 more outer range than PDS 3 (p=0.002).

## 4.3.3. Peak torque/body weight and chronological age

There was an effect for PTBW CQ (F (5, 147) =12.7; p≤0.001), PTBW CH (F (5, 147) =7.1; p≤0.001), and PTBW EH (F (5, 147) =3.7; p=0.003) between age groups. *Post hoc* analysis revealed that for CQ, the U18's and U16's had greater PTBW than the U14's and younger (p≤0.001, U16-U14 p=0.05; Figure 4.1) and the U15's showed greater PTBW than the U13's (p=0.002) and younger (p=0.009). For CH, the U18's had greater PTBW than the U13's and younger (p≤0.001), and the U16's had greater PTBW than the U14's and younger (p≤0.001, except U16-U14 p=0.012). For EH, only the U16's had greater PTBW than the U14's (p=0.024), U13's (p=0.021) and U12's (p=0.018). There were no interactions (age x dominance) for any of the PTBW variables, nor was there an effect for dominance.



\*U18 greater than U14 and younger (p≤0.001). ∞U16 greater than U14 and younger (CQ: p≤0.001, except U16 - U14 p=0.05; CH: p≤0.001, except U16 - U14 p=0.012; EH: U16 - U14 p=0.024, U16 - U13 p=0.021, U16 - U12 p=0.018). #U15 greater than U13 (p=0.002) and U12 (p=0.009). ~U18 greater than U13 and younger (p<0.001).

## Figure 4.1. PTBW for CQ, CH and EH for chronological age group analysis

## 4.3.4. Peak torque/body weight and biological age

There was an effect for PTBW CQ (F (2, 125) =14.6; p $\leq$ 0.001), PTBW CH (F (2, 125) =9.5; p $\leq$ 0.001), and PTBW EH (F (2, 125) =3.9; p=0.023) between PDS groups. *Post hoc* analysis revealed that for CQ, and CH PDS 4 had greater PTBW than PDS 2 (CQ: p=0.005, CH: p=0.007) and PDS 3 (p $\leq$ 0.001) (Figure 4.2). For EH PDS 4 had greater PTBW than PDS 3 (p=0.05).There were no interactions (PDS x dominance) for any of the PTBW variables, nor was there an effect for dominance.





## Figure 4.2. PTBW for CQ, CH and EH for biological age group analysis

### 4.3.5. Relationship between chronological and biological age

Within PDS 3 there remained an effect for chronological age group (F (4, 47) =9.0; p $\leq$ 0.001). *Post hoc* analysis revealed that for PT CQ, CH and EH the U16's had greater PT than the U14's (p =0.017,  $\leq$ 0.001, =0.030 respectively), U13's (p $\leq$ 0.001, =0.010, =0.020), and the U12's (p $\leq$ 0.001, =0.002, =0.010). For CQ and EH the U15's had greater PT than the U13's (p=0.018, =0.05 respectively) and the U12's (p=0.08, =0.002). For CH the U15's had greater PT than the U12's (p=0.05).

For PTBW CQ and CH the U16's had greater PTBW than the U12's only (p=0.033, =0.031 respectively). For EH there were no further chronological age group differences. There were no interactions (age group x dominance) for this analysis, and no between age group effects for any of the other variables. However, for PT CH and PTBW CH there was an effect for dominance (F (1, 47) =both 8.7; p=0.05) suggesting greater PTBW on the dom leg.

#### 4.3.6. Angle of peak torque and chronological age

There was an effect for AoPT CH (F (5, 147) =2.65; p=0.025) between age groups. *Post hoc* analysis revealed that the U18's showed a lower and therefore more outer range AoPT than the U13's (p=0.011) (Table 4.3, pp 74). There were no effects for AoPT CQ or EH. There were no interactions (age x dominance) for any of the AoPT variables, nor was there an effect for dominance.

#### *4.3.7.* Angle of peak torque and biological age

There was an effect for AoPT CH (F (2, 125) =6.5; p=0.002) between PDS groups. *Post hoc* analysis revealed that PDS 4 showed a lower and therefore more outer range AoPT than PDS 3 (p=0.002, Table 4.3, pp 74). There were no effects for AoPT CQ or EH. There were no interactions (PDS x dominance) for any of the AoPT variables, nor was there an effect for dominance.

## 4.3.8. Correlation between angle of peak torque and peak torque/body weight

There was a weak but significant inverse relationship between dom and ndom PTBW EH, and the corresponding AoPT (r=-0.304 and -0.316 respectively;  $p \le 0.001$ ). This suggested that a higher and therefore more inner range AoPT was associated with decreased strength (Figures 4.3 and 4.4). There were no relationships between PTBW CH and CQ and AoPT for dom or ndom legs.



Figure 4.3. Correlation between dom PTBW EH and AoPT EH



Figure 4.4. Correlation between ndom PTBW EH and AoPT EH

### 4.3.9. Muscular balance and chronological age

There was an effect for FHQ (F (5, 147) =4.2; p=0.001) between age groups. *Post hoc* analysis revealed that the U18's showed less equality (lower ratio) than the U13's (p=0.001) and U12's (p=0.012, Figure 4.5). There were no effects for CHQ. There were no interactions (age x dominance) for CHQ or FHQ variables, nor was there an effect for dominance.

# 4.3.10. Muscular balance and biological age

There was a significant main effect for FHQ (F (2, 125) =5.3; p=0.006) between PDS groups. *Post hoc* analysis revealed that PDS 4 showed less equality (lower ratio) than PDS 3 (p=0.005, Figure 4.6). There were no effects for CHQ. There were no interactions (PDS x dominance) for CHQ or FHQ variables, nor was there an effect for dominance.



\*U18 less equality than U13 (p=0.001) and U12 (p=0.012)

Figure 4.5. FHQ and CHQ for chronological age group analysis



\*PDS 4 less equality than PDS 3 (p=0.005)

Figure 4.6. FHQ and CHQ for biological age analysis

#### 4.3.11. Asymmetry (dominant:non dominant ratios)

There was an effect for CH:CH (F (5, 147) =2.4; p=0.040) between chronological age groups. *Post hoc* analysis revealed that the U16's showed greater equality (closer to 1; above 1 indicating stronger dom leg) than the U12's (p=0.017, Table 4.4). There were no other effects for CQ:CQ or EH:EH. In addition, there were no effects for CQ:CQ, CH:CH or EH:EH between biological age groups.

	Muscle balance (dom:ndom)						
Age Group	CQ:CQ	CH:CH	EH:EH				
U12	$1.00 \pm 0.21$	$1.17 \pm 0.21$	$1.04 \pm 0.17$				
U13	$1.03 \pm 0.14$	$1.09 \pm 0.16$	0.99 ± 0.17				
U14	0.97 ± 0.11	$1.08 \pm 0.15$	1.02 ± 0.11				
U15	0.97 ± 0.15	$1.00 \pm 0.20$	0.99 ± 0.12				
U16	0.99 ± 0.13	1.08± 0.16*	$1.00 \pm 0.10$				
U18	1.02 ± 0.15	$1.08 \pm 0.18$	$1.02 \pm 0.17$				
PDS2	$1.00 \pm 0.08$	1.15± 0.21	$1.07 \pm 0.14$				
PDS 3	0.97 ± 0.19	1.07 ± 0.19	$1.00 \pm 0.14$				
PDS 4	$1.01 \pm 0.13$	$1.06 \pm 0.19$	$1.02 \pm 0.14$				

Table 4.4. Muscle asymmetry (dom:ndom) ratios for CQ, CH and EH for chronological and biological age group analysis

\*U16 more equality than U12 (p=0.017), values above 1 indicate stronger dom leg.

### 4.4. Discussion

This study illustrated bilateral chronological and biological age group muscular strength and performance in a large cohort of elite male youth footballers. It was possible to accept the first hypothesis because PT and PTBW did significantly increase with both age measures. An important finding was that there were inequalities in muscular strength development between both the hamstrings and the quadriceps (PT analysis) and also inequalities between concentric and eccentric strength development (PTBW analysis) for both types of age group analysis. This may be evidence of football specific muscular strength and performance. It was also possible to reject the second hypothesis because chronological ageing appeared to exert an effect which was independent of biological age group. It was possible to accept the third hypothesis because AoPT did not show a significant relationship between AoPT EH and PTBW EH, where a more inner range AoPT was correlated with lower PTBW. For the final research question there were two interesting findings which meant that the hypothesis could not be accepted. This was due to the significant

relationship between age and FHQ, and an asymmetrical 'trainability' effect for CH:CH (dom:ndom ratio).

4.4.1. Muscular strength and performance for concentric quadriceps, concentric hamstrings and eccentric hamstrings throughout chronological and biological ageing

### Peak torque

A PT increase for CQ, CH and EH in young athletes has been extensively reported by authors using a variety of test conditions (Ellenbecker et al., 2007; Barber-Westin, Noyes and Galloway, 2006; Cometti et al., 2001; Kellis et al., 2001; Chin et al., 1992; Kramer and Balsor, 1990; Rochcongar et al., 1988). The present study agreed with this convention, observing that isokinetic PT increases significantly as ageing occurs. The present study also identified that PT increases were not consistent across the hamstring and quadriceps. The U18 and U16 age groups both had greater PT CQ than all of the younger age groups. This was in contrast to the CH and EH conditions where the U18, U16 and U15 age groups were not statistically dissimilar to each other. A possible reason for the differences may be the nature of the sport of football which requires focus on the kicking action performed by the quadriceps (Rahnama, Reilly and Lees, 2005; Howe, 1996). This effect has been linked to exposure to football training and may be independent of age and related to training history (Fousekis, Tsepis and Vagenas, 2010), though this was not specifically assessed within the scope of the present study.

The pattern of muscular strength gain reported in the present study was in agreement with Rochcongar et al. (1988) who also reported specific PT CQ gains at the U18 age group in their sample of 166 elite junior footballers. In contrast, Barber-Westin, Noyes and Galloway (2006) did not find any specific PT gains after the age of 14 in non specialised children further enhancing the evidence for football specificity in muscular strength and performance development.

Of additional interest was the descriptive pattern of PT increase in the present study, an approximate 35% increase for the U15 age group. This was likely to be very meaningful based on the variability analysis completed in Table 3.1 (pp 68) and may be related to the average peak of the pubertal growth spurt (14.0 years, Malina, Bouchard and Bar Or, 2004), and an accompanying escalation of serum androgen hormones which has been shown to significantly increase muscular strength in males and youth footballers (Hansen et al., 1999; Ramos et al., 1998). To further support this explanation, in the present study PDS 4 (advanced puberty) also showed significantly higher PT than PDS 2 and 3, and 11 of the 18 participants in the U15 age group reported themselves as PDS 4. Unfortunately it was beyond the scope of the present study to determine whether training for football influences strength development as a direct result of increase serum

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androgen hormones. However, for coaches, clinicians and trainers this may be relevant because U15 and PDS 4 appear to represent time periods for marked improvements in PT.

## Peak torque/body weight

Previous investigations have demonstrated a significant increase in PTBW with chronological ageing (Ellenbecker et al., 2007; Barber-Westin, Noyes and Galloway, 2006; Gerodimos et al., 2003; Kellis et al., 2001; Housh et al., 1996) which is in agreement with the present study. As with PT there was evidence of football specific muscular strength and performance, because the ranges of PTBW for CQ, CH and EH (1.97Nm/kg - 2.60Nm/kg, 0.98Nm/kg - 1.50Nm/kg, 1.93 - 2.22Nm/kg respectively) were systematically lower than those reported for 12 - 17 year old basketball players (Gerodimos et al., 2003). This difference may be related to the sport-specific kicking skills required for football, or alternatively skills such as repeated jumping and landing in basketball which are not as common in football (Gerodimos et al., 2003).

PTBW data also highlighted inequalities not present for PT between types of muscular contraction. The concentric conditions (CQ, CH) showed linear increases, with significant differences between every two-three yearly age groups which were likely to be meaningful considering the variability of the sample (Table 3.2, pp 68). This was in agreement with the findings of Holm, Steen and Oldstad (2005) and De Ste Croix et al. (2002) and is probably a result of controlling BW (Holm, Steen and Olstad, 2005; De Ste Croix et al., 2002). Noticeably, for PTBW EH, only the U16 age group showed a meaningful (Table 3.2. pp 68) increase compared to the U14 and U12's. This result was not anticipated because at ages 17-18 (U18) youth footballers begin training for football 'full-time'. This increase in training and game play exposure did not appear to result in greater PTBW EH for the U18's. In fact, the descriptive data suggested lower PTBW EH for the U18's than the U16's (2.15 vs. 2.29Nm/kg, dom and ndom combined). This finding may have repercussions for performance and injury risk. EH strength is considered a predictive factor for hamstring strain injury (Orchard et al., 1997) and may specifically relate to the action of the hamstrings during the late swing/early stance phase of sprinting gait (Thelen et al., 2005), which has been identified as the most susceptible time for injury (Chumanov et al., 2012; Orchard, 2012).

Another interesting finding was that the PTBW data showed lower increases between chronological age groups. This may suggest that age related increases in PT cannot be entirely explained by increases in BW (Gerodimos et al., 2003; Housh et al., 1996). Therefore, mechanisms such as increased force-production capacity with chronological and biological ageing (De Ste Croix, Deighan and Armstrong, 2003), the influence of growth and maturational factors such as increased or decreased limb length (De Ste Croix, Deighan and Armstrong, 2003), or as discussed

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previously the pubertal growth spurt and associated hormones (Hansen et al., 1999) may influence such increases.

For the present study PTBW development patterns were largely mirrored when PDS group analysis was performed, though only PDS 4 had greater PTBW EH than PDS 3, though this may not have been a meaningful change (Table 3.2, pp 68). This suggested that biological ageing did not exert an independent effect on PTBW in this cohort, and is in agreement with other authors (De Ste Croix, 2007; Maffuli, King and Helms, 1994). Despite this, PDS 4 represented a time of increased concentric torque production as compared to the mid-pubertal stages (PDS 2 and 3). Coaches, clinicians and trainers may find this of interest since no allowance is made within the English youth football academy/centre of excellence system for differing pubertal status of players within age groups, despite this possible advantage for force production.

4.4.2. Relationship between chronological and biological age, and peak torque, peak torque/body weight of concentric quadriceps, concentric hamstrings and eccentric hamstrings.

In similarity with De Ste Croix et al. (2002), Segar and Thorstensson (2000) and Maffulli, King and Helms (1994), the results of the present study suggested that chronological age exerted an independent effect upon muscular strength whereas biological age did not. This was indicated by the significant increases in PT for all of the isokinetic conditions when biological age was controlled to PDS 3 but BW was not. When BW was accounted for (PTBW) the significant independent effect for chronological age within PDS 3 was limited to the concentric conditions (CQ and CH). This may confirm the points made above suggesting that EH muscular strength increase was not linear, and did not appear to increase significantly simply through chronological ageing. At present the reasons for this finding remain to be elucidated. It may be that this could be a result of contraction specific training if eccentric contractions of the hamstrings are not targeted, and so to elicit increases in EH strength, specific exercise may be required.

4.4.3. Muscular performance pattern of angle of concentric quadriceps, concentric hamstrings and eccentric hamstrings throughout chronological and biological ageing

Data from the present study suggested that mean AoPT (with 0° equalling knee extension) was in the region of 70-78° for CQ, 50-63° for CH and 30-38° for EH. Normative AoPT has not been previously reported for youth footballers making comparison across the literature difficult, however parallels may be drawn with authors who have considered adult populations. Kannus and Beynnon (1993) reported a mean angle of 54° for CQ, and 33° for CH at 60°/s in their cohort of healthy male volunteers. They found no significant effect for age, though this may be expected because their sample was aged 18 to 40 years and was likely to be fully grown. In the present study, *post hoc* comparison of AoPT by chronological age indicated an irregular effect because SD

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were high, no clear trends were evident and the change for AoPT CH that reached significance were unlikely to be meaningful (Table 3.1, pp 68). Therefore, it was highly likely that these were the result of a type one error, a view which was shared by Knapik et al. (1983) who reported AoPT to be highly variable in their sample of healthy adult men and women. By means of explanation, it may be hypothesized from work by Brockett, Morgan and Proske (2004) and (2001) that AoPT is dependent on the length-tension relationship and the muscle-tendon complex for the muscle and joint to be tested. The length-tension relationship is based on a theory of sarcomere length, and it is highly likely that during growth and maturation sarcomere lengths are variable as myogenesis occurs (Malina, Bouchard and Bar-Or, 2004). Therefore, a possible reason for the finding may be that since the current project did not measure growth specifically AoPT may have been unlikely to relate to chronological age.

Muscular performance in terms of AoPT remains of interest for this population because of the reported alteration following hamstring injury (Brockett, Morgan and Proske, 2004). With Brockett, Morgan and Proske (2004) citing eccentric muscle damage as the cause of lasting shortened sarcomere length and, therefore, a more inner range optimum angle (Brockett, Morgan and Proske, 2004). Thus, even if AoPT is not related to chronological age, it may yet be a useful predictor of muscle strain injury; however, this would require further investigation.

### 4.4.4. The correlation between angle of peak torque and muscular strength

Similar to reports by Kannus and Beynnon (1993), the results of the present study indicated a negative correlation between AoPT and PT. The EH PTBW to AoPT relationship, although weak, was significant (p≤0.001) linking appropriately to the theorised biomechanical mechanism of hamstring injury (i.e. late swing/early stance phase in sprinting (Chumanov et al., 2012; Orchard, 2012; Orchard, 2004)) and may be anatomically described as decreased EH PTBW in outer range. This represents a potential area of interest for clinicians working with youth footballers, because eccentric exercise may favourably affect AoPT EH (Proske et al., 2004). These findings further highlight AoPT as a variable to be considered alongside muscular strength for injury prevention purposes. It may therefore be beneficial for clinicians to routinely measure AoPT EH during isokinetic evaluation.

## 4.4.5. Muscular balance and asymmetry throughout chronological and biological ageing

### Hamstrings:quadriceps ratios

An important finding of the present study was the significant decrease in FHQ through chronological and biological ageing which was in contrast to previous research (Ellenbecker et al., 2007; Ahmad et al. 2006; Barber-Westin, Noyes and Galloway, 2006; Gerodimos et al., 2003; Kellis et al., 2001). This move away from H:Q equality (1) was meaningful according to the variability of

the sample (Table 3.2, pp 68) became a significant imbalance for the U18 age group, who as previously discussed have entered 'full-time' training for football. This finding may suggest a limited focus upon EH strength training, or conversely a superior focus upon CQ strengthening, and may have implications for injury risk (Orchard et al., 1997; Jonhagen, Nemeth and Eriksson, 1994). In addition, biological age analysis suggested an additional effect for pubertal development because PDS 4, which was only 38% U18, showed a significant move away from H:Q equality when compared to PDS 3. This, again, highlights a role for EH strength training in youth football, particularly for the U18 age group, or for those at an advanced pubertal stage.

The descriptive FHQ data in the present study was comparable to Cometti et al. (2001), who reported an FHQ of approximately 0.8 for adult professional footballers. This figure was consistent with the U18 age group in our study suggesting that the muscle balance of the oldest age group category in this study was comparable with adult professionals. FHQ ranged from 1.10 to 0.85 throughout the chronological age groups which was comparable with Kellis et al. (2001) who reported a range of 1.29 to 0.76 in their sample of 10 to 17 year olds. However, in the present study FHQ was higher at all comparable levels (U12 – U18) suggesting a greater degree of EH PT or lesser degree of CQ PT. Calculations of CHQ at a slower isokinetic velocity (30°/s) (Rochcongar et al., 1988) have revealed values of 0.52 for U16 and 0.65 for U14 and U12. Others have reported a value of 0.52 for trained footballers aged 14-16 (Kellis et al., 2001). This is also in agreement with the present study which observed CHQ ranging from 0.50-0.62. Though in contrast to the aforementioned authors there was no significant increase with chronological age or PDS. A reason for this disparity may be the different pre-determined isokinetic velocities. Rochcongar et al. (1988) found significant increases only when using a velocity of 30°/s, not at 180°/s. This would suggest that if CHQ is of particular interest for a coach, trainer or clinician, an isokinetic velocity of less than 60°/s should be used (Rabin and Post, 1990).

#### Asymmetry

Analysis of dom:ndom asymmetry over chronological and biological ageing proved unremarkable with the exception of CH:CH, which showed a significant relationship with chronological age. However, the meaningfulness of this finding was questionable (Table 3.3, pp 69). The present study was, however, the first to consider this in a wide age range of young footballers, although previous authors have reported different PT for the dom and ndom leg in adults (Kellis et al., 2001; Leatt, Shepard and Plyley, 1987) and specific youth age groups (Rochcongar et al. 1988). Orchard et al. (1997) and prospectively linked altered CH:CH to hamstring injury in adult Australian footballers without reference to dominance, therefore, this type of asymmetry may be an important consideration for injury prevention. The U12 age group showed most inequality between dom and ndom legs (1.2, suggesting a stronger dom leg), though CH:CH asymmetrically

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bias toward the dom leg for all age groups. It may therefore be speculated that years of training exposure has an effect upon this variable (Kearns, Isokawa, Abe, 2001), an effect which has also been termed "trainability" (Matos and Winsley, 2007; Malina, Bouchard and Bar-Or, 2004). This phenomenon has also recently been reported for adult footballers with a reduced training history (Fousekis, Tsepis, and Vagenas, 2010). Therefore further research is required to investigate and confirm this effect, especially since significant dom:ndom asymmetry in PT has rarely been found in adult footballers (Zakas, 2006; Tourny-Chollet, L'eger and Beuret-Blanquart, 2000; Oberg et al., 1986).

## 4.5. Limitations

A possible limitation of the present study was the cross sectional design which may not control for genetics and intra-group variation to the same degree as a longitudinal design (De Ste Croix, Deighan and Armstrong, 2003). However, authors do acknowledge the practical improbability of the longitudinal design (De Ste Croix, 2007). Despite this, it remained a goal for the current project to incorporate a longitudinal element. A further limitation was that inferential statistics could not be undertaken upon PDS groups 1 and 5 because of small subject numbers. This meant that information regarding the muscular strength and performance of pre- and post-pubescent youth footballers could not be adequately considered in this chapter which limited the scope of the possible conclusions. It could also be considered a weakness that the current project did not include a direct assessment of long bone growth which would have assisted conclusions regarding the interaction between AoPT and this variable. Further literature may consider research designs which have more frequent evaluation intervals to allow for an appreciation of this possible relationship.

A final limitation was the use of the PDS in the current project. PDS grouping was as an ordinal rather than a continuous scale measure unlike skeletal age estimations done through x ray examination. This meant that, like chronological age grouping, correlational designs were not possible; however this was appropriate because external validity to playing age groups was maintained. For biological PDS grouping this was not the case as elite youth football is not organised in this manner. It was also possible that as a self reporting measure the PDS grouping was subject to error or misinterpretation by the participants. Errors of this nature may have lead to participants being placed into PDS groups incorrectly which could affect the patterns found and reported in the data adversely. Another possible limitation of the PDS was that participants ranked their perception of their pubertal development with reference to their peers. This meant

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that it was not possible to easily identify individuals who were pubertally advanced or delayed in comparison to their peers which would have been an advantage to consider as part of this study.

## 4.6. Conclusion

The results of the present study provided normative and comparative data for coaches, clinicians and trainers working with the youth football population. The inclusion of biological age analysis through the inclusion of PDS grouping added to the specificity of isokinetic evaluation but appeared to be secondary to chronological age and BW adjustment because there was no determinable independent effect. This may have been related to the limitations of the use of PDS grouping. The most important findings led to recommendations concerning muscular imbalance possibly caused by a lack of EH strength for the U18 age group which may have implications for injury risk and prevention. In addition, further research into the asymmetry noted for dom:ndom was required to understand and confirm the existence of specific asymmetrical muscular performance traits of young footballer at U12.

#### Chapter Five: Seasonal variation in the muscular strength and performance of youth footballers

#### 5.1. Introduction

The importance of monitoring seasonal variation of physiological variables in competitive sport has been widely acknowledged (Carling and Orhant, 2010; Gabbett, 2005a and b; Reilly and Peiser, 2006; Thomas and Reilly, 1979). A predominant aim of such research is to quantify the effect of sport specific training over the period of interest, and for the population. Another aim could be the identification of disruption or change to physiological performance which may predispose an individual to injury. Research of this nature can therefore be useful to coaches, clinicians and trainers for performance and injury prevention.

Youth football training has traditionally aimed to develop and improve performance of particular physical fitness parameters, including muscular strength and power (Iga et al., 2009; Stratton et al. 2004; Wein, 2001). Consequently, authors have noted that young footballers display a specific pattern of muscular strength and performance development (Iga et al., 2009; Kellis et al., 2001; Rochcongar et al., 1988; Leatt, Shephard and Plyley, 1987). There has also been suggestion that the hamstring and quadriceps groups develop dissimilarly (Forbes et al., 2009a; Iga et al, 2009; Commetti et al., 2001; Rochcongar et al., 1988) as do concentric and eccentric muscular strength (Forbes et al., 2009a), and that differences may exist bilaterally reflecting the asymmetric nature of footballers' leg dominance (Zakas, 2006). These inferences may suggest that football training and game play may have an effect upon isokinetic muscular strength and performance; however no authors to date have studied intra-seasonal changes in these parameters.

Incidence of injury in football has been shown to vary over the course of a competitive season (Hawkins et al., 2001), with peak incidence occurring after both pre-season, and after any mid season break (Petersen et al. 2010b; Hawkins et al., 2001; Hawkins and Fuller, 1999; Lewin, 1989). This pattern has also been noted in youth football (Le Gall et al. 2006; Price et al., 2004) with 'sharp' rises in injury incidence across July/August and January (Price et al., 2004). A possible reason for this is a lack of training and competition 'readiness' which may be related to detraining through rest or intense training preceding the re-start of competition which has prevented necessary adaptation (Price et al., 2004). However the finding remains largely unexplained and previous authors have not related this injury information to any intra-seasonal changes in physiological variables. Few authors to date have considered seasonal variation of isokinetic muscular strength and performance parameters in a youth football population, possibly due to the previously discussed inherent complexities of growth and maturation (De Ste Croix, 2007). A further consideration is the transitory nature of some of the age groups of youth football. An example of this would be that the entire U16 and U18 age groups rarely complete a competitive

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season because of the signing (or release) of youth training or professional contracts before the season ends. Thus, these age groups are exceptionally difficult to track.

In summary, no previous authors have considered isokinetic muscular strength and performance for youth footballers over the course of a competitive season, despite an acceptance that muscular torque and strength increases with chronological and biological ageing. In Chapter Four chronological age was found to exert an effect which was independent of the PDS analysis of biological age. Thus, for greater clarity the present study utilised chronological playing age groups alone. In addition, despite the different patterns for PT and PTBW highlighted in Chapter Four, the longitudinal nature of the present study required only the relative strength measure of PTBW and associated muscular performance (AoPT, H:Q ratios, dom:ndom asymmetry) for comparison over time.

The aim of the present study was to conduct a season-long analysis of muscular strength and performance in youth soccer players illustrating any temporal patterns of seasonal variation of muscular strength and performance. This could inform coaches, clinicians and trainers regarding injury prevention strategies should there be links to the aforementioned times of peak injury incidence as reported in the literature. Further aims were to consider the effect of chronological ageing on seasonal variation in muscular strength and performance, and to consider the stability of the data recorded in Chapter Four as to whether previous conclusions constituted enduring trends throughout a season of football training and game play.

It was hypothesised that PTBW CQ, CH and EH would increase throughout the season as chronological ageing occurs. AoPT was hypothesised to remain variable due to the transitory nature of growth, maturation and ageing. A secondary hypothesis was that muscle balance H:Q variables (CHQ, FHQ) and asymmetry (dom:ndom) would not be affected by seasonal variation due to their relative nature.

#### 5.2. Methodology

#### 5.2.1. Participants

Sixty-nine elite youth footballers belonging to the U12-U15 teams of two CoE volunteered to participate in this study. All participants and their parents/guardians completed informed consent documentation and pre-exercise medical questionnaires. No participants were suffering from musculoskeletal injury at any of the testing periods. The study was approved by the departmental and ethical procedures committee and followed the principles outlines in Declaration of Helsinki. Participants were organised by competitive playing age group because previous investigations in

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Chapter Four did not suggest an independent effect for biological ageing as measured by pubertal development.

# 5.2.2. General procedures

The procedure for this study, including isokinetic evaluation, familiarisation and assessment of chronological age over the course of the season has been outlined in Chapter Three (pp 65-69).

# 5.2.3. Data reduction

Twenty-two participants did not complete all testing due to injury or unavailability, and the incompletion rate by age group was as follows: U12 (6), U13 (4), U14 (7), U15 (5). Data analysis was only completed on those 47 players who completed all phases of the study, whose demographics are displayed in Table 5.1.

## Table 5.1. Participant demographics for SS, MS and ES

Age Group (n)	Start of Season (SS)		Mid season (MS)		End of season (ES)	
	Height (cm, x ± SD)	Weight (kg, x ± SD)	Height (cm, x̄ ± SD)	Weight (kg, x̄±SD)	Height (cm, x̄ ± SD)	Weight (kg, x̄ ± SD)
U12 (14)	147.6 ± 5.9	39.6 ± 7.3	149.8 ± 7.0	44.3 ± 8.0	150.8 ± 7.2	43.6 ± 8.7
U13 (16)	154.2 ± 8.6	45.8 ± 8.0	156.2 ± 9.0	49.8 ± 8.6	158.0 ± 9.7	50.1 ± 8.8
U14 (7)	159.6 ± 9.4~	48.4 ± 6.5~	161.9 ± 8.8~	53.6 ± 6.3~	163.5 ± 8.9~	53.9 ± 7.6~
U15 (10)	175.9 ± 3.6	62.3 ± 7.3	177.5 ± 3.3	68.6 ± 7.7	177.9 ± 3.5	67.8 ± 7.9
Total (47)	158.8 ± 12.3*	48.4 ± 10.9#	160.1 ± 12.5*	53.0 ± 12.0	161.3 ± 12.3*	53.0 ± 12.2

No significant interactions between time and age group for height and weight. \*Main effect for height over time suggesting that all participants were significantly taller at each time point (p<0.001). #All participants weigh less at SS in comparison to MS and ES (p<0.001). MS to ES not significantly different. ~U14 not significantly taller or heavier than U13, all other age groups significantly different in height and weight.

# 5.2.4. Statistical analysis

This study used a repeated measures mixed longitudinal and cross sectional design. Bilateral PT, PTBW, and associated AoPT for conditions CQ, CH, and EH were recorded along with calculations of FHQ, CHQ and dom:ndom CQ, CH and EH. Data were analyzed using a mixed model repeated measures ANOVA with post hoc SIDAK correction which was repeated for each muscle condition (PTBW CQ, CH, EH, AoPT CQ, CH, EH, and CHQ, FHQ). Higher order interaction effects were investigated, as were main effects for time (SS, MS, ES) leg dominance, and age group (U12 - U15). In addition, a mixed model ANOVA was used to investigate asymmetry (dom:ndom, CQ, CH and EH) across time and age group. Quantile-quantile (Q-Q) plots were plotted and reviewed for each variable to justify the use of parametric statistical tests. Q-Q plots suggested acceptable normality of data for each variable because there was no consistent or substantial 'sagging' nor 'rising' away from the line of normal distribution (Field, 2009). Assumptions of sphericity were investigated using Mauchly's test. If these assumptions were violated the Greenhouse-Geisser test was used

and the F value adjusted accordingly. Significance was accepted at  $p \le 0.05$  and all data are presented as  $\bar{x} \pm$  SD. For clarity, where there were no significant main effects, F values were not reported.

#### 5.3. Results

#### 5.3.1. Muscular strength and performance

#### Peak Torque/body weight

For CQ there was an effect for time (SS, MS, ES) (F (2, 86) =4.0; p=0.021). *Post hoc* analyses revealed that the MS measure was lower than the SS measure (p=0.014; Figure 5.1). There was also a significant between age group effect (F (3, 43) =2.9; p=0.044) with *post hoc* analysis revealing greater PTBW for the U15's compared to the U12's (p=0.038; Figure 5.2).



# MS lower than SS value (p=0.014) \* MS lower than SS and ES value (CH: p=0.026, 0.011 respectively EH: p=0.003, 0.004 respectively).



For CH there was an interaction between dominance and age group (F (3, 43) =3.9; p=0.015). *Post hoc* analysis revealed that the U15's had greater PTBW than the U12's (p<0.001) and U13's (p=0.002) on the dom leg. On the ndom leg the U15's had greater PTBW than all younger age groups (U12-13 p<0.001; U14 p=0.005). The U12 age group also had less PTBW than the older age groups (U13 p=0.017, U14 p=0.002, U15 p<0.001, Table 5.2 pp 93). In addition, the U12's and U13's had greater PTBW on the dom leg (p=0.001 and =0.029 respectively; Figure 5.3). For CH there was also an effect for dominance (F (1, 43) =9.6; p=0.003) and *post hoc* analysis revealed

greater PTBW CH for the dom leg (p=0.003). There was also an effect for time (F (2, 86) =5.8; p=0.004) and *post hoc* analysis revealed that the MS measure was lower than SS and ES (p=0.026 and =0.011 respectively; Figure 5.1). Finally, there was a between age group effect (F (3, 43) =4.1; p=0.012) with *post hoc* analysis revealing that the U15 age group had greater PTBW than the U12's (p=0.014; Figure 5.2).



\*U15 greater than U12 (CQ: p=0.038, CH: p=0.014)

Figure 5.2. PTBW for CQ, CH and EH by age group

For EH there was an interaction between time and age group (F (6, 86) =3.1; p=0.009). *Post hoc* analysis revealed that for the U14's and U15's PTBW EH was greater at ES than MS (p=0.006 and =0.024 respectively). The U13's had greater PTBW at SS than ES (p=0.002; Table 5.2 pp 93). The U15's also had greater PTBW at ES than the U13's (p=0.006). In addition, there was an effect for time (F (2, 86) =8.0; p=0.001) and *post hoc* analysis revealed that the MS measure was lower than SS and ES (SS: p=0.003, ES: p=0.004; Figure 5.1). There were no effects for, or interactions between, age group and dominance.


\*U12 and U13 stronger dom legs (U12: p=0.001 U13: p= 0.029)

Figure 5.3. Dom and ndom values for CH in all age groups

# Angle of peak torque

For CQ there was an interaction between time and age group (F (6, 86) =3.5; p=0.04). *Post hoc* analysis revealed that the U12's age group had an AoPT CQ which was lower and therefore more inner range than the other age groups (p=0.03). The U12's also had a more inner range AoPT CQ at SS than MS (p≤0.001) and ES (p=0.002; Table 5.3 pp 94). There was also an effect for time (F (2, 86) =10.4; p≤0.001) and *post hoc* analysis revealed that the SS AoPT CQ measure was more outer range than MS (p=0.008) and ES (p=0.001; Table 5.3). There were no effects for, or interactions between, age group and dominance. For CH there was an interaction between dominance and age group (F (3, 43) =3.8; p=0.017). *Post hoc* analysis revealed that the SS AoPT CH measure was more outer (F (2, 86) =8.5; p≤0.001) and *post hoc* analysis revealed that the SS AoPT CH measure was more outer range than ES (p≤0.001; Table 5.3). For EH there was an effect for time (F (2, 86) =18.9; p≤0.001) and *post hoc* analysis revealed that the ES measure was lower and therefore more outer range than ES (p≤0.001; Table 5.3).

	Condition		<b>SS (</b> x	± SD)	<b>MS (</b> )	k ± SD)	ES (x̄ ± SD)			
			dom	ndom	dom	ndom	dom	ndom		
		CQ	2.00 ± 0.39	2.01 ± 0.48	1.87 ± 0.22	1.86 ± 0.28	1.91 ± 0.28	1.99 ± 0.25		
		СН	1.15 ± 0.26	0.96 ± 0.23*	1.04 ± 0.13	0.97 ± 0.09*	$1.09 \pm 0.16$	1.00 ± 0.17*		
	(INITI/Kg)	EH	$2.01 \pm 0.54$	1.81 ± 0.38	1.79 ± 0.20	1.73 ± 0.27	1.93 ± 0.26	1.82 ± 0.29		
U12		СНQ	0.58 ± 0.11	0.51 ± 0.17	0.56 ± 0.08	0.53 ± 0.08	$0.58 \pm 0.10$	0.50 ± 0.07		
n=14	n:Q	FHQ	1.02 ± 0.26	0.95 ± 0.29	0.97 ± 0.14	0.95 ± 0.20	$1.03 \pm 0.20$	0.92 ± 0.14		
		cq:cq	1.03	± 0.22	1.02	± 0.10	0.96	± 0.07		
	dom:ndom	CH:CH	1.21 ±	±0.23≠	1.08	± 0.12≠	1.11 ±	: 0.21≠		
		EH:EH	1.11	$1.11 \pm 0.17$		$1.05 \pm 0.11$		$1.08 \pm 0.17$		
		CQ	2.09 ± 0.29	2.08 ± 0.39	2.10 ± 0.31	2.09 ± 0.32	2.14 ± 0.30	2.10 ± 0.30		
		СН	$1.24 \pm 0.18$	1.12 ± 0.21	$1.11 \pm 0.24$	$1.09 \pm 0.20$	$1.13 \pm 0.18$	$1.10 \pm 0.20$		
	(INM/Kg)	EH	$1.98 \pm 0.34$	2.03 ± 0.31	$1.88 \pm 0.24$	1.87 ± 0.38	1.80 ± 0.24~	1.72 ± 0.25~		
U13	U13 H:Q n=16	сно	0.60 ± 0.07	0.55 ± 0.10	0.53 ± 0.10	0.52 ± 0.07	$0.54 \pm 0.10$	0.53 ± 0.07		
n=16		FHQ	0.96 ± 0.18	$1.00 \pm 0.23$	0.91 ± 0.16	0.91 ± 0.22	0.86 ± 0.17#	0.84 ± 0.16#		
		cq:cq	1.02	± 0.12	1.01	± 0.09	1.03	± 0.11		
	dom:ndom	CH:CH	1.12	± 0.16	1.02	± 0.14	$1.04 \pm 0.14$			
		EH:EH	$0.99 \pm 0.20$		$1.03 \pm 0.20$		$1.04 \pm 0.10$			
		CQ	$2.12 \pm 0.47$	2.27 ± 0.31	2.05 ± 0.39	$2.06 \pm 0.47$	$2.32 \pm 0.49$	2.23 ± 0.55		
	(Nm/kg)	СН	$1.19 \pm 0.21$	$1.23 \pm 0.20$	$1.16 \pm 0.20$	$1.10 \pm 0.13$	$1.37 \pm 0.21$	$1.27 \pm 0.29$		
	(INIII/ Kg)	EH	$1.94 \pm 0.32$	1.88 ± 0.29	1.83 ± 0.41	$1.71 \pm 0.43$	$2.10\pm0.4\alpha$	1.97 ± 0.47α		
U14	ц.о	CHQ	0.57 ± 0.8	$0.54 \pm 0.05$	0.57 ± 0.11	0.55 ± 0.07	0.60 ± 0.09	0.57 ± 0.55		
n=7	п.ц	FHQ	$0.93 \pm 0.13$	0.83 ± 0.77	$0.91 \pm 0.19$	$0.85 \pm 0.18$	$0.91 \pm 0.11$	$0.89 \pm 0.12$		
		CQ:CQ	0.93	± 0.13	1.00	± 0.11	1.05	± 0.10		
	dom:ndom	CH:CH	0.98	± 0.17	1.05	± 0.13	1.10	± 0.09		
		EH:EH	1.03	± 0.08	1.08	± 0.14	1.08	± 0.16		
	DTR\//	CQ	2.35 ± 0.37	2.42 ± 0.25	$2.16 \pm 0.31$	$2.26 \pm 0.20$	$2.14 \pm 0.36$	$2.31 \pm 0.34$		
	(Nm/kg)	СН	1.26 ± 0.20×	1.29 ± 0.15∞	1.20 ± 0.25×	1.23 ± 0.13∞	1.24 ± 0.24×	1.25 ± 0.18∞		
	(1411)/ 16/	EH	$2.05 \pm 0.25$	$2.21 \pm 0.24$	$1.93 \pm 0.23$	$1.95 \pm 0.28$	$2.17 \pm 0.27 \alpha$	$2.10\pm0.16\alpha$		
U15	H-O	СНQ	$0.54 \pm 0.07$	$0.54 \pm 0.04$	0.56 ± 0.08	$0.54 \pm 0.04$	$0.58 \pm 0.07$	0.55 ± 0.06		
n=10	11.0	FHQ	$0.88 \pm 0.14$	$0.92 \pm 0.11$	$0.90 \pm 0.11$	$0.86 \pm 0.12$	$1.04 \pm 0.21$	$0.91 \pm 0.11$		
		CQ:CQ	0.98	± 0.14	0.96	± 0.14	0.93	± 0.12		
	dom:ndom	CH:CH	0.97	± 0.08	0.97	± 0.12	0.99	± 0.13		
		EH:EH	0.93	± 0.13	1.00	$1.00 \pm 0.16$		$1.05 \pm 0.12$		

# Table 5.2. SS, MS and ES values for PTBW CQ, CH, EH and CHQ, FHQ on dom and ndom legs

\*U12 age group less than older (U13 p=0.017, U14 p=0.002, U15 p<0.001) on the ndom leg.  $\sim$ U15 greater than all younger (U12-13 p=<0.001; U14 p=0.005) on the ndom leg. ×U15 greater than U12 (p=<0.001) and U13 (p=0.002) on the dom leg.  $\sim$ At ES U13 less than at SS (p=0.002). $\alpha$  U14 and U15 greater than at MS (p=0.006 and 0.024). # At ES U13 significantly less toward recommended than at SS (p=0.005). $\neq$ U12 more asymmetry then U15 (p=0.005)

	Condition		<b>SS (</b> x̄	± SD)	MS (x	± SD)	ES (x	± SD)
			dom	ndom	dom	ndom	dom	ndom
1112		CQ	70.4 ± 7.4*~	71.6 ± 6.5*~	78.4 ± 6.3	82.3 ± 7.9	76.2 ± 10.9	82.0 ± 10.9
012	AoPT (°)	СН	55.0 ± 15.6∞	58.2 ± 11.6∞	57.8 ± 16.3	57.8 ± 15.4	45.6 ± 11.5	49.1 ± 10.7
11-14		EH	39.0 ± 16.9	34.1 ± 12.7	35.1 ± 6.0α	37.1 ± 11.5α	30.1 ± 11.6α	29.6 ± 12.2α
	14.2	cq	80.4 ± 10.0~	80.1 ± 10.1~	79.2 ± 8.0	76.9 ± 9.3	82.8 ± 6.1	80.9 ± 8.9
013	AoPT (°)	СН	62.9 ± 15.8∞	61.9 ± 15.5∞	59.7 ± 14.1	53.6 ± 15.6	60.7 ± 12.4	59.4 ± 14.3
U=10		EH	36.1 ± 7.4	34.4 ± 10.3	34.4 ± 11.0α	30.7 ± 12.6α	30.3 ± 11.0α	30.6 ± 11.8α
111.4		cq	76.3 ± 8.4~	79.7 ± 6.3~	79.2 ± 4.4	84.5 ± 10.1	81.0 ± 10.8	80.6 ± 9.7
014	AoPT (°)	СН	54.3 ± 9.0∞	68.3 ± 6.2#∞	53.4 ± 6.9	56.0 ± 13.1#	45.6 ± 13.0	50.1 ± 15.5#
n=7		EH	30.9 ± 13.1	38.7 ± 7.2	29.0 ± 8.3α	27.7 ± 13.2α	22.0 ± 11.6α	22.0 ± 7.3α
		cq	76.4 ± 7.0~	72.8 ± 12.8~	81.1 ± 9.6	75.3 ± 9.0	81.4 ± 12.2	83.3 ± 7.4
U15 n=10	AoPT (°)	СН	63.5 ± 15.5∞	59.5 ± 13.9∞	56.3 ± 16.6	55.2 ± 13.1	55.9 ± 19.3	51.0 ± 19.2
		EH	38.6 ± 11.1	34.3 ± 9.6	39.7 ± 8.8α	34.5 ± 12.2α	27.6 ± 11.6α	25.3 ± 11.5α

## Table 5.3. SS, MS and ES values for AoPT CQ, CH, EH on dom and ndom legs

\*U12's more inner range than older (p=0.03), and at SS as compared to MS (p<0.001) and ES (p=0.002). ~SS more inner range than MS (p=0.008) and ES (p=0.001). # U14's more inner range on the ndom leg (p=0.018).  $\infty$ SS significantly more inner range than ES (p<0.001).  $\alpha$  ES more outer range than SS (p<0.001).

## 5.3.2. Muscle balance and asymmetry

#### Hamstrings:quadriceps ratios

For CHQ there was a main effect for dominance (F (1, 43) = 6.8; p=0.012). *Post hoc* analysis revealed that measures for the dom leg were closer to equality (p=0.012). There were no interactions between or main effects for time and age group.

For FHQ there was an interaction between time and age group (F (6, 86) =2.4; p=0.038). *Post hoc* analysis showed that only the U13 age group moved away from H:Q equality, and that this only occurred at the ES measure (p=0.005; Table 5.2 pp 93). At no time were the age groups different from each other. There were no effects for or interactions between, age group, time or dominance.

## Dom:ndom ratios

For CQ:CQ and EH:EH there were no interactions between time and age group, nor were there effects for time or age group. For CH:CH there were no interactions between time and age group, nor was there an effect for time. However, there was a main effect for age group (F (1,43) 4.4; p=0.09). *Post hoc* analysis revealed that the U12 had more asymmetry (above 1; indicating stronger dom leg) than the U15 (p=0.005; Table 5.2).

#### 5.4. Discussion

The aim of this study was to conduct an analysis of seasonal variation in the muscular strength and performance of youth footballers aged 11-15 years. The patterns identified may be useful for coaches, clinicians and trainers for the purposes of performance evaluation and injury prevention. The primary finding of this study was a mid-season drop in performance which existed for all PTBW variables (CQ, CH, and EH) and consequently the first hypothesis was rejected. The second hypothesis was partially accepted as H:Q and asymmetry ratios did not show any pattern of seasonal variation, with only CH:CH showing a significant relationship with age. AoPT moved toward outer range across the time points. Other notable findings acted as clarification and further evidence that PTBW for concentric contractions (CQ, CH) increased with age, whereas EH did not. A CH:CH asymmetry, specifically a stronger dom leg existed in the U12 and U13 age groups throughout the season.

## 5.4.1. Seasonal variation of muscular strength and performance

The mid-season drop (from SS to MS) in all PTBW variables was on average 6.1% (CQ: 5.1%, CH: 5.6%, EH: 7.7%), and the ES measures were on average 5.1% higher than MS (CQ: 4.0%, CH: 5.8%, EH: 5.6%). The decrease from SS to MS was significant for all PTBW variables and age groups. The increase from MS to ES was significant for all PTBW variables and age groups except CQ, and U12 and U13 EH as determined by post hoc analysis. As in the present study, seasonal variation of physiological variables has been reported in other athletic populations including adult soccer players (Carling and Orhant, 2010; Magal et al., 2009; Caldwell and Peters, 2009; Thomas and Reilly, 1979) and in adult and junior Rugby league players (Gabbett, 2005a and b). Of the aforementioned studies, only junior Rugby league players displayed a similar MS performance decline to the one observed in the present study, however direct comparison is difficult because there was no isokinetic data provided by Gabbett (2005b). Gabbett (2005b) attributed their finding to a higher match: training load and high rates of injury, but this was unlikely to be the cause in the present study because all participants were injury free at the time of testing. A possible reason for the observed MS drop was that training loads were decreased before MS testing due to a Christmas break in fixtures. The effect of unsupervised training, as is invited during this type of break, was discussed by Kovacs et al. (2007) who reported that interruptions in training resulted in significantly reduced speed and power. It should be noted in relation to this that Kovacs and colleagues (2007) investigated a strict five week break, and that the break in the present study was minimal (approx two weeks) and not rigidly controlled. Another explanation may be that lower temperature, lower levels of physical activity and higher illness rates in the winter months might contribute to decreased performance in physiological tests (Reilly and Peiser, 2006). This may be relevant due to the timing of the present study, which conducted MS

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testing in early January during the English winter and did not specifically record changes in health. A final reason may be that all age groups weighed significantly more at MS than at SS (Table 5.1, pp 89). This would have the effect of decreasing PTBW as a relative variable, in addition the changes in PTBW at MS may be at the limit of meaningfulness (Table 3.2. pp 68) due to the variability of the sample.

Nonetheless, the presence of an MS drop in muscular strength may link to the findings of Price et al. (2004) who stated that peak times for injury in youth football were immediately after preseason or after mid-season/Christmas. Since, strength deficit is an intrinsic risk for injury (Crosier, 2004; Orchard et al., 1997; van Mechelan, Hlobil and Kemper, 1992) it would be negatively affected by gains in weight and therefore the findings of the present study could provide some rationale for a post-break peak in injury rate. However, since Price et al. (2004) did not provide information regarding the type of injury which commonly occurred immediately after a break, this interpretation should be treated with caution until further research provides a solid temporal link.

For AoPT there was a consistent and significant trend for a move toward more outer range across the season. It should be noted that the magnitude of the observed changes was unlikely to be meaningful when considering the variability of the sample (Table 3.1. pp 68). Nonetheless, the hamstrings and quadriceps muscle groups did not show the same temporal patterns. For AoPT CQ this was characterised by SS, MS and ES showing differences to each other. The average percentage alteration of the AoPT across age groups was (SS to MS) 4.5% and (MS to ES) 1.7%. This pattern was emphasised for the U12 age group where AoPT CQ moved toward outer range by 11.7% between SS and MS and then stabilised between MS and ES. For AoPT CH and EH only the ES measure was more outer range, though a clear trend for a reduction in AoPT was present in the data (CH: SS to MS, -6.8%, MS to ES, -7.1%. EH: SS to MS, -6.4%, MS to ES, -18.8%). In addition, for AoPT CH the U14 age group showed a more inner range AoPT on the ndom leg which was not specific to time of evaluation. Thus, it appeared that AoPT did not vary in a similar manner to muscular strength (PTBW) for this population and therefore the observed effects required explanation.

The values reported were loosely comparable with what little normative data was available for the concentric quadriceps and hamstrings AoPT of an athletic population from Clark et al. (2005) who reported a mean AoPT CQ of 66.1° and CH of 32.5° for the small sample of nine male athletes included in their study. It is therefore possible that higher and more outer range AoPT CQ for the youth population may be influenced by the participation in football for the present study, a sport that is predominated by sport specific technical and physical activities involving muscle action of the quadriceps (Howe, 1996). If the observed changes were accepted to be meaningful, and not as a result of normal variability, the temporal pattern of a move toward outer range AoPT for all

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three muscle conditions could also be explained as a result of a learning effect for the participants, despite the efforts of the researcher to meet with the recommendations of De Ste Croix, Deighan and Armstrong (2003) for the use of isokinetic evaluation with youth populations. This argument may be supported by the lack of between age group differences reported in the study meaning that the age groups did not show significantly different temporal patterns. On the other hand, the observed move toward outer range AoPT for all variables may be as result of a football specific muscular performance training effect throughout the course of the season. This alternative argument may be supported by the fact that the U12 age group who were identified Chapter Four (pp 79) as possibly having higher and more asymmetrical 'trainability', displayed a significantly different pattern of AoPT movement to the other age groups. Unfortunately data does not currently exist which could answer this question definitively and this may be an area of interest for future research.

A final consideration was that muscle balance and asymmetry were not affected by the aforementioned MS performance drop. This was probably due to the fact that CQ, CH and EH PTBW decreased and then increased in fairly equal magnitude over the season. Thus, though PTBW dipped, MS muscle balance and dom:ndom ratios remained relatively unaffected. This may also be of interest from an injury prevention perspective because it may suggest that decreased muscular strength may have a greater relationship with injury risk (based on the findings of Price et al. (2004) on seasonal variation in injury risk) as opposed to AoPT, muscular imbalance and asymmetry as was discussed in the earlier literature review (Chapter Two).

#### 5.4.2. Longitudinal stability of muscular strength and performance findings

PTBW for CQ and CH was greater for the U15's compared to the U12's. This provides further evidence that PTBW builds in a fairly linear fashion for the hamstrings and for the quadriceps when tested concentrically (Forbes et al., 2009a and b; Ellenbecker et al., 2007; Barber-Westin, Noyes and Galloway, 2006; Gerodimos et al., 2003; Kellis et al., 2001; Housh et al., 1996). However, in similarity with the assertions in Chapter Four (pp 74), this strength increase was not evident for EH. This may further suggest that youth footballers are not increasing their PTBW EH in line with their concentric (CQ and CH) PTBW, but it can now be stated that this effect endures throughout the competitive season. This may be a concern (present or future) for injury risk and/or prevention.

The present study also highlighted CH:CH asymmetry, specifically a stronger dom leg, for the U12 and U13 age groups. This finding was interesting as very few authors to date have noted, nor indeed confirmed, an intra-seasonal pattern for any dominance related differences in adult or older youth soccer players (Zakas, 2006; Tourny-Chollet et al., 2000; Oberg et al., 1986). Thus, the

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present study extends the knowledge of leg dominance issues as it can be suggested that the trait is enduring over the course of a season. This may be of interest to coaches, clinicians and trainers when designing training tasks/activities, or when planning return to play exercises/rehabilitation from injury, or during clinical manual assessment of muscle injuries.

## 5.5. Limitations

It should be noted that the present study was afflicted with a high attrition rate of 32%, though unfortunately, this phenomenon is very common for studies of this nature. The impact of subject attrition was particularly marked in the U14 age group who lost 50% of their original number due to injury or unavailability. This may provide rationale as to why the effect size (as shown by partial eta<sup>2</sup>) for the mid-season performance drop were small (PTBW, CQ: 0.086, CH: 0.119, EH: 0.288) and it may be suggested that further research is required to confirm the practical significance of the finding.

A further limitation was the fact that only three time points were considered across the season. This may have meant that muscular strength and performance patterns concerning growth may have been missed. More time points would also allow an appreciation of a trend for falling and rising PTBW over time, potentially allowing further investigation of the phenomena. In addition, it would have been an advantage to collect data regarding: exposure to football activity, training session plans and goals, and injury (including illness) incidence as part of the present study. This would also have given additional information regarding any reasons behind the observed MS drop in PTBW.

A final limitation was that changes in health and training status (other than injury) were not monitored as part of the study. Monitoring of this nature would have allowed an appreciation of actual training time missed and so given an indication of any possible effects of detraining which could then have affected muscular strength and performance. In addition, monitoring of this nature may have allowed for closer contact with the players and their parents/guardians which may have attenuated the drop out rate experienced.

## 5.6. Conclusion

A MS drop for all PTBW variables was evident indicating that there may be a role for strengthening/injury prevention exercise immediately after a break in the competitive season (i.e. pre-season or Christmas). Muscular performance variables (CHQ, FHQ, dom:ndom CQ, CH, EH) showed no particular seasonal variation. AoPT of the hamstrings and quadriceps moved toward

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outer range across the course of the season; however it remains unclear if this was due to a training or learning effect. Regarding the stability of patterns of muscular strength and performance observed in Chapter Four, CQ and CH did increase in a manner which was not evident for EH. Additionally, CH:CH asymmetry remained evident.

Thus, the findings of the present study allowed recommendations which may assist coaches, clinicians and trainers in the design of training tasks and activities, the planning of return to play testing, and the rehabilitation and prevention of injuries. Specifically, that practitioners should be aware of a potential MS drop in muscular strength which may require intervention. Also that if an increase in EH strength is desired it needs to be specifically targeted by exercise. Finally, it should be expected that youth footballers competing in the U12 and U13 age groups may display leg to leg asymmetry.

# Chapter Six: The relationship between muscle strain injury, and muscular strength and performance in youth football

## 6.1. Introduction

Youth footballers are considered to be at a relatively high risk of injury, with an estimated 0.4 injuries per player per season causing an average absence from football activity for approximately 20 days per season (Rahnama and Manning, 2005; Price et al., 2004). Older players sustain a greater number of injuries than younger players (Price et al., 2004; McCarroll, Meany and Sieber, 1984) and early maturing (biologically advanced) players have been reported to experience a greater number of muscle strain injuries (Le Gall, Carling and Reilly, 2007). In addition, rates of peak injury incidence have tended to follow breaks from football activity (Price et al., 2004), and in Chapter Five a potential link between seasonal variation in muscular strength and performance and times of peak injury incidence was observed.

The effect of injury in youth football may be devastating with regard to skill acquisition and player development (Price et al., 2004). Furthermore, as with adult players a history of injury in youth footballers is of prime concern because of the heightened risk of re-injury after initial occurrence (Engebretsen et al., 2011; Kucera et al., 2005). Thus, the emphasis for injury prevention in this population is driven by the need to attenuate ongoing, career long injury risk and maximise development potential. The most common sites for injury in youth footballers are the ankle, thigh and knee, with the most common injury types being ligament sprains and muscle strains (Kirkendall, Marchak and Garrett Jr, 2005; Malliou et al., 2005; Junge et al., 2004; Price et al., 2004; Kakavelakis et al., 2003; Junge, Chomiak and Dvorak, 2000; Kibler, 1993). Effective injury prevention has been reported for both the ankle and the knee through proprioceptive and landing intervention programmes (Parkkari, Kujala and Kannus, 2001), however to date researchers have yet to agree upon proven risk attenuation for non contact muscle strain injuries.

In particular, hamstring muscle strains which have been reported as one of the most common injuries in English youth football (Price et al., 2004). This may be of key importance because of all muscle strain injuries, hamstring strains are very likely to re-occur, particularly in footballers (Hawkins et al., 2001). Possible reasons for the reoccurrence of hamstring injuries have been identified in the literature as decrements in strength of the hamstring group due to previous injury and ineffective rehabilitation (Crosier, 2004; Orchard et al., 1997) which could also be linked to altered muscle balance, asymmetry (H:Q or dom:ndom) and AoPT. Muscle imbalance, asymmetry and inner range AoPT have been identified as present in previously injured players (Proske et al., 2004; Orchard et al., 1997) but also noted as prospective risk factors in some studies (Orchard et al., 1997). This that athletes 'at risk' for recurrent injury or initial injury may be identified which could inform practitioners of opportunities for injury prevention.

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To date, much of the literature considering muscular strain injury in youth football has taken one of three forms. Firstly, authors have undertaken injury audits; these tend to focus on tournaments (Kibler, 1993; Schmidt-Olsen, 1985; Nilsson and Roaas, 1978), season long analysis (Kakavelakis et al., 2003; Junge et al., 2002; Junge, Chomiak and Dvorak, 2000), or multiple season analysis (Le Gall et al., 2006; Price et al., 2004; Volpi et al., 2004). Secondly, authors have retrospectively quantified differences in certain risk factors between previously injured players and those who have no injury history (Proske et al., 2004; Crosier et al., 2002; Crosier and Crielaard, 2000). Thirdly, authors (Fousekis et al., 2011; Crosier et al., 2008; Volpi et al., 2004; Bennell et al., 1998; Orchard et al., 1997) have used a prospective approach in which measurements are taken at the beginning of a given period, and then relationships examined between those who sustained injury and those who did not, thus giving information as to the predictive value of the measured variables. These types of research aim to meet the first two stages of van Mechelan, Hlobil, and Kemper's (1992) sequence of prevention by outlining the nature and causality of the injury problem. Therefore, the aim of the current study was to complete the first two stages of van Mechelan, Hlobil and Kemper's (1992) sequence of prevention, by gathering descriptive, retrospective and prospective information regarding thigh musculature strains in a cohort of elite male youth footballers. Special interest was reserved for the hamstring muscle group because the earlier review of literature (Chapter Two) suggested that this injury may have the greatest scope for prevention, in addition to being one of the most common injuries sustained in youth football (Price et al., 2004). However, information regarding all thigh muscle strains was of interest due to the findings of Price et al. (2004) who stated that this area was commonly injured in English youth footballers and would therefore be of comparative interest. In contrast to Chapter Five, both chronological and biological age were considered in this study because previous research has identified particular relationships with each type of ageing.

It was hypothesised that the injury audit data of the present study would be comparable to that of other authors who have investigated thigh musculature injury rates. It was hypothesised that previous injury would be retrospectively linked with altered isokinetic muscular strength and performance, and that altered isokinetic muscular strength and performance, and previous injury would be prospectively linked with subsequent injury.

# 6.2. Methodology

## 6.2.1. Participants

Of the one hundred and fifty two elite male youth football participants who volunteered for the current project (Chapter Three), 147 completed SS isokinetic evaluation and reported previous injury history using a designated reporting form (Appendix E). These participants formed the

chronological age sample for the injury audit and retrospective analysis. One hundred and thirty four of these participants also completed biological age analysis through the PDS, of which 128 also reported previous injury history, comprising the biological age sample for the injury audit and retrospective analysis. Over the course of the competitive season an incompletion rate of 66% (98 participants) was recorded, leaving 50 participants who went on to complete MS and ES isokinetic evaluation and completed self reporting of thigh muscle strain injuries throughout the entire competitive season. All participants and their parents/guardians completed informed consent documentation and pre-exercise medical questionnaires. The study was approved by the departmental and University ethical procedures committee and followed the principles outlined in the Declaration of Helsinki. The demographics of all participants, grouped by chronological and biological age are illustrated in Table 6.1. The demographics of the 50 participants included in the prospective analysis were: age,  $13.4 \pm 1.7$  years, height,  $160.4 \pm 12.7$  cm, weight,  $50.2 \pm 11.4$  kg (n= 50).

	Descriptive a	nd retrospective a	nalysis ( ± SD)
Chronological Age Group (n)	Age (years)	Height (cm)	Weight (kg)
<b>U12</b> (n = 21)	11.7 ± 0.3	148.6 ± 6.5	41.7 ± 7.8
<b>U13</b> (n = 25)	$12.6 \pm 0.3$	157.0 ± 8.6	48.3 ± 9.4#
<b>U14</b> (n = 27)	13.7 ± 0.3	162.5 ± 9.8	51.1 ± 10.6
<b>U15</b> (n = 20)	14.6 ± 0.3	175.0 ± 4.6*	63.7 ± 7.6*
<b>U16</b> (n = 26)	15.7 ± 0.3	$174.8 \pm 6.6^*$	63.1 ± 6.7*
<b>U18</b> (n = 28)	17.1 ± 0.6	$178.9 \pm 4.6^*$	70.2 ± 6.3*
<b>Total</b> (n = 147)	14.2 ± 0.4	166.1 ± 6.8	56.4 ± 9.3
Biological Age (PDS group) (n)			
<b>PDS 1</b> (n = 1)	11.1	147.0	41.5
<b>PDS 2</b> (n = 20)	$12.2 \pm 0.9$	152.1 ± 9.5	44.2 ± 12.1
<b>PDS 3</b> (n = 52)	13.7 ± 1.4	161.2 ± 11.0	51.0 ± 10.5
<b>PDS 4</b> (n = 56)	15.7 ± 1.4	176.3 ± 6.3	65.3 ± 8.0
<b>PDS 5</b> (n = 5)	16.0 ± 2.2	173.5 ± 16.9	66.0 ± 19.1
<b>Total</b> (n = 134)	14.4 ± 1.9	162.0 ± 8.7	53.6 ± 9.9

Table 6.1. Participant demographics for the descriptive and retrospective analysis

\*U15, U16, U18 not significantly different in height or weight. #U13 not significantly different in weight to U12 or U14. All other age groups significantly different in height and weight. All PDS groups (2 - 4) significantly different in height and weight.

# 6.2.2. General procedures

The procedure for this study, including isokinetic evaluation, familiarisation and assessment of both ageing variables has been outlined in Chapter Three (pp 65-69).

#### 6.2.3. Injury history

Injury was defined as an ailment of a physical nature which occurs in a player resultant of football activity (Fuller et al., 2006). This was explained to the players as part of the familiarisation session outlined in Chapter Three (pp 69). Injury data was collected using the self-reporting form which players were required to fill in each time they attended the laboratory. At the first visit (familiarisation) the information collected related to thigh muscle strain injury history (Hx), and the players were asked to record (with assistance of their parent/guardian if required): 1) if they had ever sustained a muscle strain of the hamstrings (dom/ndom), quadriceps (dom/ndom), and the adductors (dom/ndom) and 2) if they had sustained an injury to those muscles in the last 12 months (Hx12). Recurrent injuries for players were first asked to report (with assistance of their parent/guardian if required) whether they had sustained a thigh muscle strain injury since their last visit to the laboratory. If they responded affirmatively they were asked to report the location and diagnosis of the injury as given by the club medical staff. Players were allowed to report more than one injury at this time. At the ES visit to the laboratory players completed the same procedure as at MS.

#### 6.2.4. Injury audit analysis

The data regarding thigh muscle injury Hx was then collated so that information could be gained as to the total number of players who had a thigh muscle strain Hx (any muscle), or the total number of players who had an Hx for the hamstrings, quadriceps and adductor muscle groups. Information was also gathered as to the total number of injuries sustained, which accounted for the multiple injury reporting of some players. All of the above information was also collected for recent injury history, (Hx12) defined as occurring within the 12 months prior to the familiarisation session. All data was then arranged for analysis by biological age group (PDS group), chronological age group and the collated U12-U14 and U15-U18 age categories. This was due to previous findings (Forbes et al., 2009a and b) which suggested that CH and CQ PTBW increases every twothree years of competitive playing age group.

#### 6.2.5. Statistical analysis

Retrospective relationships between Hx12 and the isokinetic muscular performance of all participants were determined using a one-way ANOVA with *post hoc* SIDAK correction where required. This included: group (injured x non injured) for the dom and ndom leg of the hamstrings and quadriceps, for each of the variables PTBW CQ, CH, EH, AoPT CQ, CH, EH, H:Q (CHQ and FHQ) and asymmetry (dom:ndom CQ, CH and EH). Quantile-quantile (Q-Q) plots were plotted and reviewed for each variable to justify the use of parametric statistical tests. Q-Q plots suggested

acceptable normality of data for each variable because there was no consistent or substantial 'sagging' nor 'rising' away from the line of normal distribution (Field, 2009). For clarity, where hamstring injury history was reported, differences were only investigated to the hamstring muscle group. The opposite was true for the quadriceps. Adductor injuries were not included in statistical analysis because of the isolated sagittal plane nature of the isokinetic dynamometry and appear only in descriptive data. In addition, the ANOVA was not performed between chronological playing age group and biological PDS group due to low participant numbers.

For prospective analysis, the relationship between the dependent variable (thigh muscle injuries across the course of the competitive season (yes/no)) and the independent variables (start of season isokinetic and profile data) was investigated using logistical regression analysis as performed by (Fousekis et al., 2011). This type of analysis allows the researcher to "predict which of two categories a person is likely to belong to given certain other information" (Field, 2009, pg 265) and allows for a mixture of interval and binomial data types. The specific independent variables added to the experimental model were the following empirically observed 'risk' factors for muscle strain injury: increased height (Venturelli et al., 2011), age category (U12-14 or U15-18; Price et al., 2004), dominance asymmetry (CH: CH, Orchard et al., 1997) and previous thigh muscle injury (dom or ndom hamstring, quadriceps or adductors (yes/no), Engebretsen et al., 2011; Kucera et al., 2005). This allowed for construction of experimental and null models which were tested for their 'fit' to the data, resulting in a log likelihood statistic for each. 'Fit' is determined by a low log likelihood statistic and the two models may be termed significantly different ( $p \le 0.05$ ; Chi-squared  $(X^2 - 1)$  if the value for each shows enough divergence. This comparison is included in the logistic regression analysis to allow the researcher to determine whether the inclusion of selected independent variables into the experimental model allows for a greater explanation of the data set than mathematics alone.

A 'backward stepwise' logistical regression was utilised. This consists of the experimental model starting with all possible independent variables included (listed above), and then removal of any variables which do not have a substantial effect on the predictive capability and fit of the model as a whole (Field, 2009). This method was chosen due to the reported criticisms of forward stepwise models (Field, 2009), and because of the presence of previous literature in the field which allows for theoretical reasoning of the independent variables to be included.

A further output for each independent variable as a result of logistical regression is an analysis of the likelihood of an event, or odds ratio (in this case injury), occurring to an individual which is determined from the co-efficient (B). The odds ratio is the probability of an event/injury occurring vs. the probability of that event not occurring (Anderson et al., 2003). It is normally presented along with its 95% confidence limits (Anderson et al., 2003). For example, an odds ratio of 3.0

would indicate that the presence of the independent variable results in a three times higher probability of the dependant event occurring. Nagelkerke effect size estimations (R<sup>2</sup>) was also analysed and reported as Field (2009) stated that the Cox and Snell test may be flawed because the maximal value cannot be reached. The Nagelkerke test may overcome this (Field, 2009).

Throughout the study, significance was accepted at the p $\leq$ 0.05 level, and all data are presented as  $\bar{x} \pm$  SD. For clarity, during retrospective analysis where there were no significant main effects, F values were not reported.

# 6.3. Results

# 6.3.1. Injury audit

The results of SS injury audit are illustrated in Table 6.2. Table 6.2 highlights Hx and Hx12 for chronological and biological age groups and collated age categories as well information regarding the percentage of injuries which occurred for the hamstrings, quadriceps and adductor muscle groups, and dominant leg. Also outlined is the number of injuries sustained per player and the total number of injuries which occurred.

		Mus	Muscle strain injury incidence			s (of total no.)	%Quadricep	s (of total no.)	%Adductors (of total no.)	
		Total number of	Total							
		injuries	Injuries/player Hx	% dom		Hx dom		Hx dom		Hx dom
Age group	n =	Hx (12)	(12)	injured Hx	Hx (12)	injured	Hx (12)	injured	Hx (12)	injured
U12	21	14 (7)	0.67 (0.33)	64.3	64.3 (85.7)	55.6	14.3 (14.3)	100.0	21.4 (0.0)	66.7
U13	25	18 (9)	0.72 (0.36)	55.6	61.1 (66.7)	54.5	16.7 (22.2)	66.7	22.2 (11.1)	50.0
U14	27	27 (13)	1.00 (0.48)	51.9	40.7 (46.2)	36.4	29.6 (30.8)	50.0	22.2 (7.7)	66.7
U15	20	25 (15)	1.25 (0.75)	56.0	52.0 (66.7)	61.5	12.0 (13.3)	33.3	36.0 (26.7)	55.6
U16	26	30 (19)	1.15 (0.73)	60.0	46.7 (21.1)	71.4	20.0 (31.6)	50.0	33.3 (31.6)	50.0
U18	28	31 (19)	1.11 (0.68)	64.5	32.3 (42.1)	50.0	32.3 (36.8)	70.0	35.5 (21.1)	72.7
U12 - U14	73	59 (29)	0.80 (0.40)	55.9	54.2 (65.5)	50.0	22.1 (24.1)	61.5	23.7 (10.3)	64.3
U15 - U18	74	86 (53)	1.16 (0.72)	60.5	43.0 (41.5)	62.2	22.1 (28.3)	57.9	34.9 (26.4)	60.0
Total	147	145 (82)	0.99 (0.56)	58.6	47.6 (50.0)	56.5	22.1 (26.8)	59.4	30.3 (20.7)	61.4
PDS 2	20	21 (12)	1.05 (0.60)	61.9	66.7 (83.3)	42.9	9.5 (16.7)	100.0	23.8 (0.0)	80.0
PDS 3	52	47 (23)	0.94 (0.44)	61.7	48.9 (52.2)	69.6	21.3 (30.4)	60.0	29.8 (17.4)	50.0
PDS 4	56	60 (40)	1.07 (0.71)	56.7	40.0 (35.0)	50.0	26.7 (30.0)	56.2	31.7 (30.0)	63.2
Total	128	128 (75)	1.00 (0.59)	59.4	47.7 (48.0)	55.7	21.9 (28.0)	60.7	29.7 (21.3)	60.5

Hx = total injuries suffered; (12) = injuries suffered in the last 12 months; no. = number

#### Chronological age

Table 6.2 illustrates that for the 147 participants 145 muscle strain injuries were reported, with 82 occurring in the last 12 months. This meant that almost each player had an Hx of muscle strain injury (0.99) and that 0.56 of players had an Hx12. The most commonly injured muscle group was the hamstrings (46.7/50.0% of all injuries), followed by the adductors (30.3/20.7%), then by the quadriceps (22.1/26.8%). All of the muscle groups had a higher number of injuries (Hx and Hx12) on the dom leg (58%).

## Effect of age group

The highest amount of injuries per player occurred at U15 (Hx 1.25, Hx12 0.75), however there was very little difference between the U14 (Hx 1.00, Hx12 0.48), U16 (Hx 1.15, Hx12 0.73) and U18 (Hx 1.11, Hx12 0.68). The lowest amount of injuries per player occurred at U12 (Hx 0.67, Hx12 0.33) and there was a steady increase at U13 (Hx 0.72, Hx12 0.36) and U14 (Hx 1.00, Hx12 0.48). The highest number of injuries (Hx 31, Hx12 19) occurred at U18 though this age group also had the most participants (28). The lowest number of injuries occurred at U12 (Hx 14, Hx12 7) though the U15 age group had the least participants (20). Regarding asymmetry of injury distribution, the U14 age group were the only age group to report more ndom hamstring injuries (36.4% dom), and equal dom and ndom quadriceps injuries. The U16 age group also had an equal number of dom and ndom quadriceps and adductor injuries (50%), as did the U13 age group for the adductors, and the U18 for the hamstrings. In terms of the most common type of muscle injured there was no clear difference between age groups. The U18 age group reported an even spread of muscle strain injury type (Hx, hamstrings: 32.3%, quadriceps: 32.3%, adductors: 35.5%). Though for Hx12 (hamstrings: 42.1%, quadriceps: 36.8%, adductors: 21.1%), this pattern was not discernible. All other age groups reported most injuries to the hamstrings, then the adductors, then the quadriceps except the U14's who reported a higher Hx and Hx12 of quadriceps than adductor injuries.

### Age category

The U15-U18 age category reported higher amount of injuries per player (Hx 1.16, Hx12 0.72) than the U12-U14 age category (Hx 0.80, Hx12 0.40). They also reported a greater number of total injuries both Hx and Hx12 (59/29 and 86/53) though participant numbers (73 and 74) were relatively equal. Both age categories had similar types of muscle strain injury Hx with the hamstrings most commonly reported (54.2% and 54.2%), followed by the adductors (34.9% and 23.7%), then the quadriceps (both 22.1%). For Hx12 the hamstrings remained the most commonly reported injury (42.5% and 65.5%), however for both age categories the quadriceps (28.3% and 24.1%) were more frequently injured than the adductors (26.4% and 10.3%). The dom leg had

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more Hx and Hx12 for both age categories and all muscle injury types, except for the U12 - U14 hamstrings which reported equal dom and ndom hamstring injuries.

# Biological age

Table 6.2 illustrates that of the 128 participants who completed the PDS (PDS groups 2, 3 and 4) each player had an Hx of muscle strain injury (1.00) and that 0.59 of players had an Hx12. From these participants 128 muscle strain injuries were reported, with 75 occurring within the last 12 months. Similarly to chronological age comparison, the most common muscle group to have Hx/Hx12 of injury was the hamstrings (47.7/48.0%), followed by the adductors (29.7/21.3%), then by the quadriceps (21.9/28.0%). All of the muscle groups had a higher number of injuries (Hx and Hx12) on the dom leg, leading to the dom leg accounting for over 55% of all injuries.

#### Effect of PDS group

The highest amount of injuries per player occurred in PDS 4 (Hx 1.07, Hx12 0.71), however there was very little difference between PDS 4 and 2 (Hx 1.05, Hx12 0.60). The lowest amount of injuries per player occurred in PDS 3 (Hx 0.94, Hx12 0.44). The highest number of injuries (Hx 60, Hx12 40) occurred in PDS 4 however this group also had the most participants (56). The lowest number of injuries occurred in PDS 2 (Hx 21, Hx12 12) though PDS 2 had far fewer participants (20). In terms of the most common type of muscle injured, the PDS groups did show some differences. For Hx all groups reported the highest percentage of injuries to the hamstrings, followed by the adductors, and then the quadriceps. For Hx12 none of the groups followed this pattern. The hamstrings remained the most commonly injured but the percentage fell as PDS group increased (PDS 2 83.3, PDS 3 52.2, PDS 4 35.0). For PDS 4 the quadriceps and adductors were equal (30%), for PDS 3 the quadriceps were more commonly injured then the adductors (30.4/17.4%) and for PDS 2 the opposite was true (0.0/16.7%) with no injuries occurring to the quadriceps.

## 6.3.2. Retrospective analysis

#### Hamstrings

For Hx12 of an injury to the dom hamstrings the injured group had less PTBW CH and EH on the dom leg ((F (1, 135) 4.7; p=0.032) and (F (1, 135) 3.8; p=0.05)) in comparison to the uninjured group (Figure 6.1). The injured group also had more inner range AoPT CH (F (1, 135) 5.0; p=0.03) on the dom leg in comparison to the uninjured group (Figure 6.2). There were no between group effects for: dom AoPT EH, CQ:CQ, CH:CH, EH:EH, CHQ and FHQ. For Hx12 of an injury to the ndom hamstrings, the injured group were not different to the non injured group for any of the variables: ndom PTBW CH, and EH, CQ:CQ, CH:CH, EH:EH, AoPT CH, EH, CHQ and FHQ (Tables 6.3 and 6.4 pp 110-111).



# Injured group less PTBW (p=0.032).\* Injured group less PTBW (p=0.05).





<sup>\*</sup> Injured group more inner range (p=0.03).

## Quadriceps

For Hx12 of an injury to the dom quadriceps, the injured group were not different to the non injured group for any of the variables: ndom PTBW CQ, CQ:CQ, CH:CH, EH:EH, AoPT CQ, CHQ and FHQ (Table 6.3 and 6.4 pp 110-111). For Hx12 of an injury to the ndom quadriceps, the injured group had greater PTBW CQ on the ndom leg (F (1, 135) 8.2; p=0.005) in comparison to the uninjured group (Tables 6.3 and 6.4). There were no between group effects for: dom AoPT EH, CQ:CQ, CH:CH, EH:EH, CHQ and FHQ.

Figure 6.2. AoPT of participants with and without an Hx12 of dom leg hamstring injury

	Grouping			PTBV	V (N/kg)					Ao	PT (°)		
	(n)	c	Q	C	Н		EH		cQ		СН		EH
	()	dom	ndom	dom	ndom	dom	ndom	dom	ndom	dom	ndom	dom	ndom
	Injured	-	-	1.16 ±	1.09 ±	1.94 ±	1.99 ±	-	-	61.9 ±	62.6 ±	37.1 ±	34.2 ±
Dom H	(n=21)			0.20*	0.20	0.33#	0.34			12.6~	17.2	10.1	12.1
Injury	Non	-	-	1.29 ±	1.22 ±	2.13 ±	2.11 ±	-	-	55.2 ±	56.5 ±	34.4 ±	35.0 ±
(Hx12)	injured			0.26*	0.28	0.41#	0.40			12.6~	12.3	12.0	12.6
	(n=116)												
Ndom	Injured	-	-	1.37 ±	1.26 ±	2.23 ±	2.11 ±	-	-	54.4 ±	56.5 ±	37.6 ±	33.7 ±
Н	(n=16)			0.35	0.35	0.58	0.58			11.56	13.5	9.5	12.4
Injury	Non	-	-	1.26 ±	1.19 ±	2.08 ±	2.08 ±	-	-	56.5 ±	57.5 ±	34.4 ±	35.1 ±
(Hx12)	injured			0.23	0.26	0.38	0.36			13.0	13.3	12.0	12.6
	(n=121)												
D	Injured	2.46 ±	2.58 ±	-	-	-	-	76.3 ±	70.6 ±	-	-	-	-
Dom Q	(n=13)	0.42	0.35					8.1	6.5				
injury	Non	2.24 ±	2.27 ±	-	-	-	-	75.9 ±	77.0 ±	-	-	-	-
(Hx12)	injured	0.50	0.47					8.1	9.6				
	(n=124)												
Ndom	Injured	2.60 ±	2.71 ±	-	-	-	-	75.5 ±	73.8 ±	-	-	-	-
Q	(n=9)	0.27	0.33×					5.0	6.2				
Injury	Non	2.24 ±	2.27 ±	-	-	-	-	75.9 ±	76.6 ±	-	-	-	-
(Hx12)	injured	0.50	0.46×					8.3	9.7				
. ,	(n=128)												

Table 6.3. Descriptive data for Hx12 of dom and ndom hamstring and quadriceps injury by group (injured/non injured).

\* less than NI on dom leg (p=0.032). # less than NI on dom leg (p=0.05). ~ more inner range than NI on dom leg (p=0.03). × I group greater than NI on ndom leg (p=0.005).

	Grouping (n)		H: Q	ratios		dom:ndom ratios		
		с	HQ	F	HQ	CQ:CQ	CH:CH	EH:EH
		dom	ndom	dom	ndom			
Dom	Injured (n=21)	0.55 ± 0.07	0.85 ± 0.31	0.92 ± 0.17	0.99 ± 0.27	$1.04 \pm 0.18$	$1.08 \pm 0.16$	0.99 ± 0.13
H Injury (Hx12)	Non injured (n=116)	0.58 ± 0.10	0.75 ± 0.20	0.97 ± 0.24	0.93 ± 0.21	0.99 ± 0.14	1.08 ± 0.19	1.02 ± 0.14
Ndom	Injured (n=16)	0.56 ± 0.08	0.77 ± 0.21	0.91 ± 0.13	0.89 ± 0.15	$1.02 \pm 0.12$	1.11 ± 0.13	1.07 ± 0.13
H Injury (Hy12)	Non injured (n=121)	0.58 ± 0.10	0.77 ± 0.22	0.96 ± 0.24	0.95 ± 0.22	0.99 ± 0.15	1.08 ± 0.19	$1.00 \pm 0.14$
(11/12)								
Dom	Injured (n=13)	0.57 ± 0.08	0.89 ± 0.17	$0.91 \pm 0.21$	$0.84 \pm 0.19$	$0.96 \pm 0.11$	$1.07 \pm 0.12$	$1.04 \pm 0.12$
Q Injury (Hx12)	Non injured (n=124)	0.57 ± 0.10	0.76 ± 0.22	0.96 ± 0.23	0.95 ± 0.22	1.00 ± 0.15	1.08 ± 0.19	1.01 ± 0.14
Ndom	Injured (n=9)	0.55 ± 0.04	0.78 ± 0.12	0.85 ± 0.07	0.86 ± 0.17	0.96 ± 0.11	1.03 ± 0.05	0.96 ± 0.09
Q Injury (Hx12)	Non injured (n=128)	0.58 ± 0.10	0.77 ± 0.22	0.97 ± 0.24	0.94 ± 0.22	1.00 ± 0.15	1.08 ± 0.19	1.02 ± 0.14

Table 6.4. Descriptive data for Hx12 of dom and ndom hamstring and quadriceps injury by group (injured/non injured).

#### 6.3.3. Prospective analysis

Over the course of the season eight injuries were reported to eight players; these included: four hamstring strains (2x dom, 2 x ndom), three adductor strains (dom x2, ndom x 1), and one ndom quadriceps strain. This equated to 0.16 muscle strain injuries per player across the season.

### Logistic regression

The experimental model is outlined in Table 6.5. This model showed the lowest possible log likelihood statistic of 38.69, compared to the null model value of 43.97. These values were not significantly different, meaning that the experimental model did not 'fit' to the data set better than the null. Table 6.5 displays the odds ratios for the experimental model which only included age category and CH: CH after backwards stepwise regression. The odds ratios suggest that neither independent variable significantly increased the probability of injury when present in the model. The Nagelkerke effect size estimation ( $R^2$ ) was low, and the Chi-squared ( $X^2$  -1) also showed that the experimental model was not significantly different (p=0.07) to the null (constant).

Table 6.5. Results of logistic regression analysis for muscle strain injuries over the course of the competitive season.

	<b>B</b> (SE) (co-efficient of independent variable (standard error))	p value	Odds Ratio (95% CI)
Constant (null model)	2.56 (2.98)	0.39	
Age category	-1.2 (0.84)	0.15	0.30 (0.06-1.57)
сн:сн	-3.44 (3.03)	0.26	0.03 (0.00-12.13)

*R*<sup>2</sup> (effect size) = 0.17 (Nagelkerke). Model *X*<sup>2</sup> -1 = 5.27 p=0.07

#### 6.4. Discussion

The aim of the present study was to gather information regarding thigh muscle strains in a cohort of elite male youth footballers using descriptive, retrospective and prospective approaches. It was hoped that this would inform the first two stages of the sequence of prevention (van Mechelan, Hlobil and Kemper, 1992). In the case of the descriptive injury audit data it was found that the overall injury rate in the present study was comparable to previous literature, though consideration must be given to the limitations of a self reporting approach. For the retrospective approach, the hypothesis that previous injury would be retrospectively linked with altered muscular performance was accepted because the group who reported Hx12 of hamstring strains had significantly decreased CH and EH PTBW, and also a more inner range AoPT CH than the uninjured group. In addition, the group who reported an Hx12 of quadriceps strains had significantly decreased PTBW CQ as compared to the uninjured group. It should be noted that these results could have been due to the injury rather than the cause. For the prospective approach, no relationship between SS isokinetic data, injury profile, and subsequent thigh muscle injury could be established. Logistic regression analysis did not result in an experimental model which was significantly better 'fitted' than the null model. Thus, the hypothesis was rejected.

#### 6.4.1. Injury audit

In the present study the percentage of players who reported Hx of muscle strain injury alone was 56.5%. This figure could be considered abnormally high compared to Kucera et al. (2005) at 59.7% and Emery, Meeuwisse and Hartman (2005) at 36.5% who considered all injury types. It was also higher than the 48.6% reported by Junge, Chomiak and Dvorak (2000) who only considered muscle strain injury. Kucera et al. (2005) and Emery, Meeuwisse and Hartman (2005) performed full injury audits on 1483 and 317 mixed sex cohorts respectively. A possible reason for the difference in findings may be the way that injury information was collected and recorded. Emery, Meeuwisse and Hartman (2005) used a therapist referral to a sports medic for time loss injuries only which may account for their lower percentage while Kucera et al. (2005) used a coach reporting system. Junge, Chomiak and Dvorak (2000), whose findings were most similar to the present study, also used a self reporting approach. The amount of injuries per player (1.16) of the present study may also be considered high when compared to Price et al. (2004) who reported 0.40 injuries per player per season. This difference was less when Hx12 were considered (0.56) and this links appropriately to the different methodologies. Price et al. (2004) recorded injury incidence over two competitive seasons whereas the present study considered both full Hx (over many years) and Hx12. Thus, only Hx12 is appropriately comparable. However, since Price et al. (2004) also considered all injury types further reasoning to elucidate different findings was appropriate. Another possible reason for the high reported percentage of muscle strain injury Hx in the present study was that errors in recall may be possible when using a self reporting approach (Fuller et al., 2007; Junge and Dvorak, 2000). For example, if only Hx12 of muscle strain injury is included in the present study the figure becomes 39.5% of players injured, 0.56 injuries per player. This may eliminate a source of possible error as recall may be improved over the shorter time frame.

# Effect of age

In the present study the presence of an Hx and Hx12 of muscle strain injury increased with chronological age category, this is in agreement with other authors (Le Gall et al., 2006; Price et al., 2004; Yde and Neilsen, 1990). The increased exposure in training and game situations as standard of play progresses may explain this finding. This may be of interest for coaches, clinicians and trainers as it could be argued that injury prevention strategies should be targeted at older

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players. However, there was very little difference in number of injuries per player between the U14, U15, U16 and U18 age groups. The U18 age group displayed a slightly more even distribution of the three types of muscle strain injury in comparison to the other age groups, and with reference to this it was noted that hamstring Hx and Hx12 appeared to drop in percentage as chronological ageing progressed (though it remained the most common type of muscle strain). This finding may be intuitive because the U18 age group may show a summative figure building from younger age groups. Another possibility is that the full-time nature of youth training may expose U18 players to slightly different risks.

No pattern was discernible for a relationship between Hx and Hx12 of muscle strain injury for biological age. This is in contrast to Johnson, Doherty and Freemont (2009) who found maturity to be a useful predictor of injury in their sample, but used a very different methodology to the present study by including estimation of skeletal age. PDS 4 reported the highest injuries per player and this was in agreement with Le Gall, Carling and Reilly (2007) who postulated that the increases may be attributed to increased risk taking behaviour of biologically more advanced players where chronological age remains the same. Risk taking behaviours were not controlled in the present study and may not explain the observed findings because PDS 2, not 3, actually reported the second highest injuries per player. However, PDS 2 was a somewhat smaller sample than PDS 3 and 4 and therefore the low numbers may have skewed the analysis. PDS 4 also showed a similar pattern to the chronologically older age groups in that the percentage of hamstring Hx and Hx12 was comparatively less. PDS 4 contained almost all U18 participants which may explain this finding.

#### Asymmetry

An important finding of the muscle strain injury audit was that more players reported a Hx or Hx12 of muscle strain injury to the dom leg (58.6%) and that this was true regardless of age (biological and chronological), and muscle injured. This is in agreement with Woods et al. (2004) who reported that 53% of hamstring strain injuries occurred on the dom leg in senior players and Price et al. (2004) who documented that 54% of all injuries occurred on the dom leg. Further comparison of this finding was difficult as past authors have offered no consideration of leg dominance in their analysis. Therefore, it should be noted that more research is needed in this area, especially since previous literature (Forbes et al., 2009b; Rochcongar et al., 1988) has reported differing development patterns for muscular strength and performance with reference to leg dominance in youth football.

#### Muscle strain injury type

A final important finding was that more players reported an Hx and Hx12 of the hamstrings than the adductors or quadriceps. This was in agreement with previous authors (Malliou et al., 2005; Price et al., 2004), though many more authors were discounted from comparative analysis because they did not stipulate the type of injury that occurred at the thigh (Le Gall et al., 2006; Junge et al., 2004; Kakavelakis et al., 2003; Junge, Chomiak and Dvorak, 2000). In addition, more players reported an Hx and Hx12 for the adductors than the quadriceps which is also in agreement with previous literature (Price et al., 2004).

In summary, the descriptive findings of the present study were comparable in some areas to other literature. Major discrepancies in findings may be explained by the diverse methodologies used by the different authors.

#### 6.4.2. Retrospective analysis

The main finding for this analysis was that a relationship between Hx/Hx12 and altered muscular strength and performance existed, though the magnitude of the differences reported were at the limit of meaningfulness based on the variability of the sample (Table 3.2, pp 68). This was evident for a history of injury to the dom hamstrings which contained the highest number of participants who reported an Hx12 (n = 21). The previously injured group displayed a pattern which was somewhat consistent with the observations of Crosier and Crielaard (2000) because AoPT CH of the hamstrings was more inner range. However, Crosier and Crielaard (2000) also found a difference between previously injured and non-injured FHQ which was not found in the present study. A possible reason for this difference was the type of methodology used; the present study compared previously injured and non-injured individuals, but only considered either the injured or non-injured limb for differences. This approach is possibly more rigid than that used by Crosier and Crielaard (2000) who compared the legs of individuals who had sustained a unilateral recurrent hamstring strain. A methodological concern with the bilateral comparison is that there may be 'normal' individual variation between the dom and ndom muscular performance (Zakas, 2006; Leatt, Shephard and Plyley, 1987) which could lead to an increased risk of a type 1 error.

For those with an Hx12 of dom hamstring strains there was also evidence of decreased PTBW (CH: 0.1%, EH: 9%) which is similar to the findings of Crosier et al. (2002) who reported deficits of 11% and 10% respectively. This may suggest that rehabilitation of the injury was inadequate (Crosier et al., 2008), or it may be that the deficit was present as a result of functional imbalance due to football (Fousekis et al., 2011, Fousekis, Tsepsis and Vaganas, 2010) and contributed to the injury aetiology. In contrast, the previously injured ndom quadriceps group displayed greater PTBW in that muscle group than their non injured teammates. This may suggest that quadriceps injuries

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were rehabilitated more effectively than the hamstrings for this group of elite male youth footballers, or may have simply been a stronger muscle group prior to injury. The nature of the retrospective design means that no cause and effect can be inferred which meant that the use of the prospective design in addition was particularly valuable.

#### 6.4.3. Prospective analysis

The prospective muscle strain injury incidence recorded in the present study (0.16) was lower than that recorded in other comparable literature (0.24 per player per season, calculated from Price et al., 2004). However, Price et al. (2004), unlike the present study, did not specify their finding to the thigh musculature and considered all muscular strains to the lower limb. This could mean that the lower finding in the present study may be due to the fact that calf strains were not included. Indeed, when the incidence of calf strains was calculated from Price et al. (2004) they accounted for 0.08 injuries per player per season which links appropriately.

Regarding logistic regression analysis, the present study failed to identify a prospective relationship between isokinetic and individual profile variables, and subsequent muscular strain injury. The best experimental model in the present study only included the empirically evidenced risk factors of increased age (category) and asymmetry (CH:CH), and was not significantly different to a mathematical (null) model alone. This was in contrast to Fousekis et al. (2011) where the authors also used a logistic regression design. Their experimental model for hamstring injuries identified EH strength asymmetry and leg length asymmetry as crucial factors raising the probability of suffering a hamstring strain by a factor of approximately three (odds ratios of 3.88 and 3.80 respectively). Their models also included previous injury; however Fousekis et al. (2011) actually found that this decreased the risk of subsequent injury in their sample. A possible reason for the different findings of the present study and that of Fousekis et al. (2011) was the number of participants in the study, and the number of injuries sustained over the course of the period of interest, and that these authors considered adult professional footballers. The present study only included 50 participants with only four hamstring strains recorded over the course of the season, whereas Fousekis et al. (2011) had at least double that number of participants and injuries. These larger participant numbers ensured that the experimental model had sufficient power (Fousekis et al., 2011) unlike the present study.

Another possibility for the differences may be the population used by the present study. Youth footballers who are growing and developing may be more likely to have altered injury aetiology compared to professional footballers due to the variable biomechanical and physiological effects of puberty (Le Gall et al., 2006). This difference could have resulted in the poorly 'fitted'

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experimental model, which was theoretically linked to both adult and youth cited injury risk factors.

## 6.5. Limitations

The present study was affected by a high incompletion rate (66%) which limited the validity of the prospective analysis. This meant that the results were somewhat difficult to generalise to the wider youth football population, and may have accounted for the poor 'fit' of the experimental model. This was unfortunate since the field of logistic regression analysis appears to show promise as a statistical technique to assess the multi-factorial nature of injury aetiology. A further limitation was the use of self reporting injury forms to collate injury incidence and injury history data. This meant that the present study did not meet the 'gold standard' for injury research, as ideally medical notes from a qualified clinician should prove more objective (Fuller et al., 2007). Unfortunately, these limitations were unavoidable due to logistic and time restraints from the involved academy clubs, however future research should seek to control these variables to a greater extent.

# 6.6. Conclusions

Regarding the injury audit, it was evident that the history of muscle strain injury observed in the present study was higher for older youth players (U15 - U18) and that this increase may be as a result of longer exposure (more 'played' seasons and increased length of games). Biological age analysis of injury history incidence was not found to exert an additional influence or different pattern to that of chronological ageing. Thus, coaches, clinicians and trainers may wish to target chronologically older youth footballers for preventative intervention strategies. Regarding the retrospective analysis, the finding that a history of hamstring muscle injury showed a relationship with altered isokinetic muscular performance may highlight a need for isokinetic screening of injured players. This could help to ensure that rehabilitation of injuries is objectively and adequate measured. However, because the present study did not find a prospective and predictive link between isokinetic muscular performance and subsequent injury, further research should take place before preventative screening is considered warranted, and stage two of the sequence of prevention (van Mechelan, Hlobil and Kemper, 1992) can be considered complete.

Chapter Seven: The effects of an eight week hamstring strengthening programme on the isokinetic muscular performance of elite male youth footballers

## 7.1. Introduction

Hamstring muscle strains are one of the most common injuries for young footballers (Price et al., 2004). In addition, hamstring strains are highly likely to re-occur after initial trauma, thus increasing a player's time spent away from training and competition exponentially (Hawkins et al., 2001), and often result in discernible isokinetic muscular performance alteration (Dauty, Potiron-Josse and Rochcongar, 2003; Crosier et al., 2002; Crosier and Crielaard, 2000). It is perhaps for these reasons that the literature regarding risk and prevention of hamstring injury is so extensive.

Numerous researchers have attempted to identify 'risk' factors for hamstring injury (Fousekis et al., 2011; Engebretsen et al., 2010; Croisier, 2004). Many have highlighted traditionally accepted risk factors; for example: inappropriate warm-up or flexibility, decrements in strength of the hamstring group, previous injury, and ineffective rehabilitation (Crosier, 2004; Orchard et al., 1997). While others have considered indirect factors such as H:Q imbalance (Coombs and Garbutt, 2002), asymmetry (Orchard et al., 1997) and kinetic chain or stabilising dysfunctions (Wallden and Walters, 2005; Leetun et al., 2004). To date, these risk factors have been empirically linked with injury incidence via prospective and retrospective studies. Unfortunately, the role of each factor remains equivocal, as do the interactions between them. This lack of agreement has resulted in a plethora of preventative interventions which aim to bring about beneficial physiological adaptations which may decrease injury risk.

Previous preventative strategies have included: coach education (Soligard et al., 2008; Olsen et al., 2005), manipulation of warm-up (Soligard et al., 2008), increasing muscle flexibility (Arnason et al., 2007), specific muscular strengthening (Price et al., 2004; Ekstrand and Gillquist, 1983), and restoration of H:Q balance and leg to leg symmetry (Beneka et al., 2005). Other researchers have targeted alterations to AoPT (Brockett, Morgan and Proske, 2004 and 2001) through specific retraining of the hamstrings. Wallden and Walters (2005) and Leetun et al. (2004) also suggested that the hamstrings may be 'mis-used' as major core/lumbo-pelvic stabilisers, in addition to the anatomical role as a knee flexor and prevention of anterior tibial translation (Stone and Stone, 2000). These authors (Wallden and Walters, 2005; Leetun et al., 2004) intimated that any intervention to strengthen the hamstring should therefore consider the kinetic chain. Unfortunately, many of these strategies have only demonstrated theoretical or associated successes, largely because very few authors have actually tracked ongoing injury incidence after the intervention programme has been completed.

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In contrast, eccentric strengthening of the hamstrings has been shown empirically to reduce injury incidence (Peterson et al. 2010; Arnason et al., 2007; Askling, Karlsson and Thorstensson, 2003). It may also be beneficial to: redress thigh musculature imbalance (Kaminski, Wabberson and Murphy, 1998), increase strength (Askling, Karlsson and Thorstensson, 2003; Mjolsnes et al., 2001; Kaminski, Wabberson and Murphy, 1998), and move AoPT toward outer range (Clark et al., 2005; Proske et al., 2004; Brockett, Morgan and Proske, 2001). The hamstring musculature may be targeted eccentrically by completing exercises such as the nordic lowers and by plyometric exercises such as bounding (Wilkerson et al., 2004). Many researchers (Arnason et al., 2007; Brooks et al., 2006; Clark et al., 2005; Askling, Karlsson and Thorstensson, 2003; Mjolsnes et al., 2001; Brockett, Morgan and Proske, 2000; Kaminski, Wabberson, 2003; Mjolsnes et al., 2001; Brockett, Morgan and Proske, 2000; Kaminski, Wabberson and Murphy, 1998) have used these exercises to varying degrees of success. In addition, FIFA have recently developed the F11 and F11+ (F-Marc, 2005) which include eccentric hamstring exercises, and additionally includes a core stability exercise ('the bench'), the success of this programme for performance and injury prevention has been investigated (Brito et al., 2010; Kilding, Tunstall and Kuzmic, 2008; Steffen et al., 2008a and b) with varying degrees of success.

The purpose of the present study was to evaluate the muscular strength and performance outcomes of an exercise intervention targeting the hamstrings of a cohort of elite male youth footballers. The U18 age group was targeted because previous research has suggested that this age group may be an opportune and appropriate time to introduce an intervention programme targeting the hamstring musculature (Forbes et al., 2009a and b). In addition, comparison of the research by Hawkins et al. (2001) and Price et al. (2004) suggested that the U18 age group suffered less injuries than their adult counterparts, meaning that a confounding history of hamstring strain was less likely (Price et al., 2004) and that there may be benefit from preventative approaches. A final purpose was to evaluate through discussion the effect of a randomised vs. targeted approach to injury prevention for the intervention group.

The intervention strategy was informed by the F11+ (F-Marc, 2005), the reported success of the nordic lower (Arnason et al., 2007; Mjolsnes et al., 2001), and the insights of Wallden and Walters (2005) and Leetun et al. (2004) regarding the kinetic chain. The three exercises chosen are all included in the F11+ and were designed to target the hamstring muscle functions (as outlined in Table 1.1 (pp 5) and Figure 1.2 (pp 6)) in three ways. The nordic lower allows progression of exercise toward outer range eccentric loading of the hamstring through the lengthening contraction needed to lower the torso. By including the 'pulling up' component the concentric knee flexion action was also targeted. Plyometric bounding targeted the function of the hamstrings to resist anterior translation of the tibia under load imposed by the quadriceps contraction. The 'bench' exercise targeted the hamstrings indirectly by training the core and

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gluteal musculature as stabilisers, this consideration of the kinetic chain was designed to allow a decreased load on the hamstring musculature as a bi-articular stabiliser, i.e. reducing the need to use and stabilise extension of the hip, thus allowing greater function/strength distally at the knee.

It was hypothesised that the PTBW CH and EH would significantly increase for the intervention group. A secondary hypothesis was that the H:Q ratios (FHQ, CHQ) would improve by moving significantly toward equality (1). Thirdly, that the AoPT EH would move significantly more toward outer range (a less flexed knee position) and fourthly, that due to the bilateral nature of the exercise intervention dom:ndom CH and EH would move toward equality (1).

## 7.2. Methodology

# 7.2.1. Participants

The design of the present study was a non-randomised controlled study of independent groups with repeated measures, using a convenient sample of U18 elite youth footballers (n = 16; age 16.8  $\pm$  0.6 years) from one CoE. Half of the participants were assigned to a control group (n=8) after initial testing and another eight completed the exercise intervention programme. In order to assign participants to groups, participants were ranked 1-10 in order of their FHQ performance and assigned via odd and even number placing.

All participants were free from injury at the time of initial testing, were informed about the study (Appendix F) and completed a pre-exercise medical questionnaire, informed consent, height, weight and leg dominance assessment (which leg they kick with) and were informed of their right to withdraw at any time (all as outlined in Chapter Three). The study was approved by the departmental and University ethical procedures committee and followed the principles outlined in the Declaration of Helsinki. Participant demographics are displayed in Table 7.1.

Table 7.1. Participant demographic	lab	le 7.1.	Particip	oant d	emogra	phics
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		Pre interven	tion session	Post intervention session		
Group	Age (years)	Height (cm)	Weight (kg)	Height (cm)	Weight (kg)	
		$\bar{x} \pm SD$	$\bar{x} \pm SD$	x ± SD	$\bar{x} \pm SD$	
Control (n=6)	16.7 ± 0.5	179.4 <b>±</b> 4.7	75.6 ± 9.1	178.9 ± 5.5	76.8 ± 9.1	
Experimental (n=7)	16.5 ± 0.5	181.1 ± 6.9	68.9 ± 8.5	181.0 ± 4.7	$69.0 \pm 9.1$	

No significant differences existed for participant demographics at pre or post session

# 7.2.2. General procedures

Isokinetic evaluation took place before and after an exercise intervention programme. The exercise intervention programme took place over eight weeks with specific sessions taking place twice a week (16 sessions). The programme of exercise was conducted early in the football season. It began mid-way through the club's pre-season training to avoid the counterproductive

presence of a high volume of aerobic activity (Hickson, 1980), and continued into the first four weeks of the competitive season. The club Physiotherapist documented any minor injuries which prevented participants from completing the exercise sessions and the missed sessions were completed during one to one sessions with the Physiotherapist or a Graduate Sport Rehabilitator (GSR) at a later date (within the same week of the programme period).

# 7.2.3. Initial isokinetic evaluation

The isokinetic evaluation took place using the procedures outlined in Chapter Three (pp 68).

# 7.2.4. Exercise intervention programme

The participants completed two sessions of exercises post training each week and attendance was recorded. Sessions took place after training (afternoon) to maintain the effects of strength training (Small et al., 2009; Hickson, 1980). The specific exercises and their progressions over the programme period are outlined in Table 7.2. Week one/two shows recommended guidelines modified from the F11+ (F-Marc, 2005) and Mjolsnes et al. (2004), which were then progressed as described. As control measures, all sessions and exercise techniques were taught and supervised by a GSR or Physiotherapist.

## Table 7.2. Outline of exercise intervention programme

Exercise	Week 1 -2	Week 3 - 4	Week 5 - 6	Week 7 - 8
The Bench	1. Hold for 15s	1. Hold for 20s	1. Hold for 25s	1. Hold for 30s
	2. Lift one leg (15s)	2. Lift one leg (20s)	2. Lift one leg (25s)	2. Lift one leg (30s)
0	3. Lift other leg (15s)	3. Lift other leg (20s)	3. Lift other leg (25s)	3. Lift other leg (30s)
			-Rest for 10s betwee	en 1,2 and 3. Repeat twice
Bounding	30m x 2	30m x 3/4	30m x 5/6	30m x 7/8
				-2 min rest between sets
Nordic Lower	2 x 6/8 reps	2 x 10/12 reps	3 x 6/8 reps	3 x 10/12 reps
$\int_{1}^{\infty}$	-To incorporate lowering a	nd pulling back component lowering. i.	ts, progress to individual l e. should get closer to 90°	evel of control of angle of as progression continues

## 7.2.5. Post intervention isokinetic evaluation

Upon completing the intervention programme (wk 9), all participants again completed the isokinetic procedure described previously in Chapter Three (pp 68).

#### 7.2.6. Data reduction

One participant from the experimental group and two participants from the control group were forced to withdraw from the study due to unavailability or serious injury. Attendance was controlled to 75% (12/16) of the sessions because on occasion players were required to 'rest' in order to maintain their availability for selection for higher level fixtures such as first team games. Ultimately, two of the intervention group attended 12 sessions, one attended 14 sessions, three attended 15 and only one attended 16 (100%) of the sessions.

## 7.2.7. Statistical analysis

Bilateral PT, PTBW, and associated AoPT for conditions CQ, CH, and EH were recorded along with calculations of FHQ, CHQ and dom:ndom. Only data from those participants who completed the study were included in statistical analysis. Data were analysed using SPSS version 16 (Chigago, IL, USA). A mixed model repeated measures ANOVA was used to investigate interactions (group (control/intervention) x leg (dom/ndom) x time (pre/post)) for the variables PTBW and AoPT CQ, CH, EH, FHQ and CHQ. An additional repeated measures ANOVA was used to investigate (group x time) for dom:ndom CQ, CH and EH. Quantile-quantile (Q-Q) plots were plotted and reviewed for each variable to justify the use of parametric statistical tests. Q-Q plots suggested acceptable normality of data for each variable because there was no consistent or substantial 'sagging' nor 'rising' away from the line of normal distribution (Field, 2009). In the instance of significant ANOVA findings, *post hoc* analysis was completed using a SIDAK correction. Significance was accepted at  $p \le 0.05$  and for clarity F values were only presented where significant effects were observed. All data were presented  $\bar{x} \pm SD$ .

## 7.3. Results

## 7.3.1. Muscular strength and performance

#### Peak torque/body weight

There were no between group effects for the intervention for PTBW CQ, CH or EH. For CQ and EH there were interactions between time and dominance; F(1, 11)=4.8; p=0.05 and F(1,11)=8.6; p=0.14). *Post hoc* analysis suggested no further effects for CQ, however EH analysis indicated that the ndom leg was stronger post intervention (p=0.036; Table 7.3). For CH there was an effect for dominance (F(1, 11) = 7.2; p=0.021) with greater PTBW CH on the dom leg (Table 7.3) for both groups.

## Angle of peak torque

For AoPT CH there was an interaction between time and group (F (1, 11) =4.9; p=0.048), however *post hoc* analysis revealed no further effects. For AoPT CH there was also a between group effect (F (1, 11) =8.8; p=0.013). Analysis revealed that the intervention group had a more inner range AoPT CH than the control (control: 44.6°, intervention: 59.2°; Table 7.3) throughout. For CQ and EH there were no effects for group, time or leg, and no interactions.

		Pre Intervention		Post Intervention	
		Control (x ± SD)	Intervention (x ± SD)	Control (x ± SD)	Intervention (x ± SD)
PTBW CQ	dom	2.44 ± 0.27	2.56 ± 0.15	2.47 ± 0.28	2.42 ± 0.22
(Nm/kg)	ndom	2.52 ± 0.36	$2.54 \pm 0.24$	$2.34 \pm 0.31$	2.29 ± 0.29
PTBW CH	dom	$1.30 \pm 0.17 \#$	1.30 ± 0.45#	1.34 ± 0.34#	1.46 ± 0.22#
(Nm/kg)	ndom	$1.18 \pm 0.24$	$1.33 \pm 0.26$	$1.18 \pm 0.09$	$1.36 \pm 0.41$
PTBW EH	dom	2.07 ± 0.29	$2.00 \pm 0.48$	$1.96 \pm 0.29$	$2.14 \pm 0.44$
(Nm/kg)	ndom	$1.87 \pm 0.23$	$1.90 \pm 0.34$	$1.99 \pm 0.18^*$	2.26 ± 0.33*
AoPT CQ	dom	83.1 ± 15.0	78.3 ± 6.7	80.0 ± 10.3	78.2 ± 6.3
(°)	ndom	78.5 ± 8.4	76.4 ± 6.5	77.9 ± 10.5	81.7 ± 6.0
AoPT CH	dom	$45.6 \pm 6.4$	54.2 ± 10.8~	38.9 ± 6.3	62.7 ± 18.6~
(°)	ndom	50.8 ± 12.9	55.4 ± 12.4~	43.3 ± 12.5	64.4 ± 12.1~
AoPT EH	dom	36.4 ± 19.7	42.9 ± 14.8	33.0 ± 14.0	30.1 ± 13.2
(°)	ndom	41.7 ± 17.4	42.4 ± 10.0	39.6 ± 20.4	39.4 ± 16.4

\* Both groups higher than pre intervention (p=0.036). # Dom leg stronger throughout (p=0.021). ~Intervention group higher than control (p=0.013)

## 7.3.2. Muscle balance and asymmetry

## Hamstrings:quadriceps ratios

There were no between group effects for CHQ or FHQ. For CHQ there was an interaction between time and dominance (F(1, 11)= 5.7; p=0.036). *Post hoc* analysis revealed that post intervention the ndom leg CHQ ratio was closer to 1 (pre: 0.495- post: 0.572; p $\leq$ 0.001; Figure 7.1). There were also effects for time for FHQ (F(1, 11)= 12.6; p=0.005; Figure 7.2), and CHQ (F(1, 11)= 8.2; p=0.016) respectively. Analysis revealed that in both groups the ratio moved closer to 1 post intervention.



\*Ndom leg closer to equality (1) after intervention (p<0.001).

Figure 7.1. Combined control and intervention group pre and post intervention CHQ for dom and ndom legs



\*post intervention both legs closer to equality (p≤0.005)

Figure 7.2. Combined dom and ndom pre and post intervention FHQ

# Dom:ndom ratios

There were no interactions between group and time for CQ:CQ, CH:CH or EH:EH, and there were also no effects between groups. For EH:EH there was an effect for time (F (1, 11) 10.0; p=0.009) which suggested a move toward equality (above 1 +0.08 to below 1 -0.03) by both groups (Figure 7.3). There were no effects for time for CQ:CQ and CH:CH.



\*both groups moved toward equality (p=0.009)

Figure 7.3. Dom:ndom ratios for both groups pre and post intervention

# 7.3.3. Pre to post intervention changes

In order to analyse the variables measured in the present study using a comparative approach, the percentage change over the course of the intervention was determined for all variables (Table 7.4). For clarity, changes of less than one percent were recorded as zero.

Table 7.4 suggests that nearly all changes pre-post intervention were greater for the intervention group. Of particular note were the changes to CH and EH PTBW which were approximately 12% greater for the intervention group and the FHQ ratio which was approximately 15% greater for the intervention group. The changes in PTBW CH were also reflected in the intervention group value for CH:CH as they were greater on the dom leg. AoPT CH also showed a notable difference between control and intervention group regarding pre-post intervention change. This was characterised by the control group showing a move toward outer range by approximately 15%, and the intervention group showing a similar magnitude of change toward inner range (Table 7.4).

		Change over time (%)	
		Control	Intervention
PTBW CQ (Nm/kg)	dom	+ 1.2	-5.5
	ndom	-7.1	-9.8
PTBW CH (Nm/kg)	dom	+3.1	+12.3
	ndom	0	+2.3
PTBW EH (Nm/kg)	dom	-5.3	+7.0
	ndom	+6.4	+18.9
СНQ	dom	+1.7	+17.8
	ndom	+9.2	+11.5
FHQ	dom	+10.4	+24.6
	ndom	+13.3	+30.2
AoPT CQ (°)	dom	-3.8	0
	ndom	0	+6.9
AoPT CH (°)	dom	-14.6	+15.6
	ndom	-14.7	+16.2
AoPT EH (°)	dom	-9.3	-29.8
	ndom	-5.0	-7.1
Dom:ndom	CQ:CQ	+8.4	+5.6
	CH:CH	0	+16.9
	EH:EH	-10.8	-7.6

#### Table 7.4. Percentage changes over time for all variables

#### 7.4. Discussion

The aim of the present study was to investigate the effects of an exercise intervention programme which was designed to strengthen and improve the performance of the hamstrings in youth soccer players. It was hypothesised that the programme of exercise would significantly increase eccentric hamstring strength and improve FHQ and CHQ ratios. Further hypotheses were that AoPT EH would move toward outer range (decrease in degrees) and that dom:ndom ratios would remain unaffected due to the bilateral nature of the exercise intervention. All hypotheses were rejected, as there were no significant differences observed between the control and exercise intervention groups in post intervention testing, and EH:EH was affected by time. Significant improvements in FHQ and EH:EH were noted and PTBW EH and CHQ improved for the ndom leg for all participants.

The most notable finding of the present study was that the control and exercise intervention groups were not significantly different after the exercise intervention. This could suggest that early-season football training alone, which was completed by all participants, significantly improved hamstring muscular strength and performance. Equally, the exercise intervention used in the present study may not have been sufficient to result in additional strength gains when used in conjunction to early season training. A further possibility may be the presence of some contamination from experimental to control groups which resulted due to the participants belonging to the same competitive team and possibly sharing knowledge/practice of the intervention. This effect has been termed 'diffusion' (Craven, Marsh, and Jayasinghe, 2001) and is

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considered common when a class, or for the purposes of the present study a team, is split to form control and intervention groups.

# 7.4.1. Muscular strength and performance

## Peak torque/body weight

Another notable finding of the present study was the magnitude of PTBW EH improvement for all participants which was significant on the ndom leg. This improvement was likely to be meaningful based on the variability of the sample (Table 3.2, pp 68) and may be partially explained by the improvements in the exercise intervention group which were greater than the control by approximately 0.25 (Nm/kg; 13%). This type of finding was echoed by Askling, Karlsson and Thorstensson (2003), Brito et al. (2010), Kaminski, Wabbersen and Murphy (1998) and Mjolsnes et al. (2004) who reported: 15%, 14.3%, 37.7% and 11% increases respectively. However, unlike the present study, the aforementioned authors did note significant differences between control and intervention groups. A possible reason for the difference in the above findings is the age of the participants in the current project. The adaptations to resistance training in youth participants may alter in volume and causality due to the inherent transitory nature of growth and development, leading to differing levels of neural adaptation, development of muscle, and hormonal influence (De Ste Croix, Deighan and Armstrong, 2003). This would seem plausible since only Steffen et al. (2008a and b) have previously reported isokinetic data for youth participants. These authors also reported no significant changes as a result of 10 weeks of injury prevention exercises using the F11+. Furthermore, Sailor and Berg (1987) found that adults did indeed show greater strength gains in response to resistance training when compared to adolescents. Consequently, it may be that the exercise intervention in the present study was not sufficient to bring about significant adaptations for youth footballers when compared to pre season football activity alone.

Another possible reason for the contradictory lack of between group differences was the differing nature and length of the exercise intervention programme. The present study was eight weeks in length and comprised of both direct eccentric hamstring exercise (bounding, nordic lower) and an indirect exercise for the core (the bench). This was somewhat shorter than the 10 week programmes utilised by Brito et al. (2010), Mjolsnes et al. (2004), Askling, Karlsson and Thorstensson (2003) and Kaminski, Wabberson and Murphy (1998). Interestingly, all but Brito et al. (2010) completed an exercise intervention programme consisting of direct eccentric exercise alone. However, Brito et al. (2010) completed the entire F11+ programme and was therefore less targeted toward the hamstrings than the present study. This would suggest that the length of an intervention programme is important, and had the present study lasted for 10 weeks a significant

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post intervention difference between groups may have been achieved. This supposition is further evidenced by the trend for increased improvement in the exercise intervention group, therefore, coaches, clinicians and trainers may be recommended to complete exercise interventions of 10 weeks in future research projects. Additionally, the high speed nature of exercises such as bounding may not be expected to show adaptation at the slow isokinetic speed used to test the participants. This suggests that future researchers may wish to consider a range of isokinetic testing speeds with multi-exercise intervention strategies.

Another important finding of the present study was the decrease in PTBW CQ over the course of the exercise intervention programme which was particularly prominent on the ndom leg. This finding was also likely to be meaningful based on the variability of the sample (Table 3.2, pp 68). Similar findings have been reported by Steffen et al. (2008b), and a significant decrease was recorded by Clark et al. (2005). However, in contrast Brito et al. (2010) recorded a significant increase. This is confounding since Brito et al. (2010) and Steffen et al. (2008b) completed the same intervention programme (the F11+). Steffen et al. (2008a and b) encountered poor adherence for their exercise intervention which may have negatively influenced their findings, however Clark et al. (2005) had their participants perform nordic lowers for only four weeks. The decrease in performance observed by the present study and by Clark et al. (2005) may be explained via detraining (ACSM, 2002) if the exercise intervention took the place of normal training. Though in the present study, the participants were expected to complete the intervention exercises in addition to their normal training load, and so decreased quadriceps strength was not expected. Nevertheless, there may have been some changes to the participants normal training regime due to the logistics of fitting in additional sessions; alternatively, it may have been an anomalous finding representative of a type II error. Future research may be warranted to confirm the relationship between eccentric training of the hamstrings and quadriceps performance.

# Angle of peak torque

The effect of eccentric training on AoPT has only been considered by a few authors to date. It has been postulated as important by Brockett, Morgan and Proske (2001) who retrospectively linked the variable to hamstring injury. They suggested that athletes who had a history of injury had a significantly more inner range AoPT EH than those who did not. Practically, this means that the hamstrings would be considered at their peak strength in a more flexed knee position, when the opposite has been considered desirable for optimal function and injury prevention (Brockett, Morgan and Proske, 2004 and 2001). The present study recorded a decreased AoPT EH angle post exercise intervention for all participants, which was in agreement with Clark et al. (2005) and Brockett, Morgan and Proske (2001). Though it was not significant and may not have been

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meaningful (Table 3.1, pp 68). It should be noted however that Brockett, Morgan and Proske (2001) reported the effect immediately post exercise rather than after an exercise intervention programme. The present study also recorded that the movement of AoPT EH toward outer range was accompanied by AoPT CH moving toward inner range for the intervention group. Post exercise and post exercise intervention change in AoPT may be explained by a change in the length-tension relationship of the hamstring musculature, specifically the addition of sarcomeres in series which may allow the muscle to operate more or less effectively at different lengths (Brockett, Morgan and Proske, 2001). However, since the present study appears to be the first to consider AoPT CH in addition to EH further research should seek to verify the existence of the effects noted.

## 7.4.2. Muscle balance and asymmetry

## Hamstrings:quadriceps ratios

An important finding of the present study was that both the control and exercise intervention groups improved their FHQ ratio, however the exercise intervention group improved three times more than the control on the ndom leg (30.2%) and twice as much on the dom leg (24.6%). This finding was on the limit of meaningfulness according to the variability of the sample (Table 3.2, pp 68) and was in contrast to Mjolsnes et al. (2004) who recorded a significant, but only 9% improvement in their eccentric exercise group. The difference in magnitude of change may be explained by the decreases to PTBW CQ found in the present study which were not present for Mjolsnes et al. (2004). A decrease in PTBW CQ, combined with the increase in PTBW EH would have the effect of intensifying the muscle balance improvements. Indeed, when the effect of the PTBW CQ decrement is removed from the FHQ calculation the improvement is comparable (13% dom/ndom leg combined). A similar pattern and causality exists for CHQ, and if a similar calculation is performed then the improvement in CHQ becomes 6% as opposed to 14.7% (dom/ndom combined). This value better reflects the modest improvements which were noted in PTBW CH, and the finding that the exercise intervention group had higher PTBW CH throughout which was probably a chance occurrence. Furthermore, the findings then reflect that a more eccentrically based training programme will have only a small cross over training effect for concentric contraction (ACSM, 2002; Mjolsnes et al., 2004; Kaminski, Wabberson and Murphy, 1998). This is of consequence because it indicates that injury prevention exercises must be specific to contraction type if they are to be effective.

#### Asymmetry

The present study highlighted an unexpected pattern of different training adaptations to the dom and ndom legs which was in agreement with Brito et al. (2010) and Clark et al. (2005). Overall,

there was a greater variation of change on the ndom leg, characterised by greater improvements in PTBW EH, and FHQ, and greater losses in PTBW CQ. However, the opposite pattern was true for PTBW CH, AoPT EH and CHQ with the dom leg showing greater changes. Analysis of the EH:EH change over time would also appear to suggest greater changes to the ndom leg over time because the ratio moved from above 1 (stronger dom leg) to below 1 (stronger ndom leg). Brito et al. (2010) also reported greater changes for EH measurements on the ndom leg, as did Clark et al. (2005) though they only measured hamstring performance concentrically. A possible reason for the greater improvements in the ndom leg may be the training status and pre exercise intervention strength of the hamstrings. For this group of youth footballers the hamstrings were stronger on the dom leg and so it is feasible that the ndom hamstrings were less trained. Commonly, less trained individuals make greater gains during resistance exercise programmes then their trained counterparts (ACSM, 2002). This may be evidenced by the atypically high improvements (37.7%) in PTBW EH recorded by Kaminski, Wabberson and Murphy (1998) who were the only authors to use untrained participants. Alternatively, it may be that the leg to leg differences are influenced specifically and even individually by the nordic lower exercise (Clark et al., 2005). The nordic lower is a bilateral exercise but has appeared in previous literature to affect the legs in a unilateral manner. Clark et al. (2005) reported that regardless of dominance, the leg which displayed more outer range strength (lower AoPT EH and CH) at the initial evaluation showed greater adaptation as a result of the exercise. This may be because at a point during the lowering exercise the leg with higher outer range strength would be required to control the descending torso to a greater degree than the contra-lateral leg. This is an interesting argument which requires further examination because it may have practical application for injury prevention if the preventative exercise could in fact create greater leg to leg disparity in this way.

## 7.4.3. Randomised vs. targeted approach

Analysis of the data for the intervention group participants that a randomised approach as used in the present study could be considered limited in effectiveness, even though the intervention was targeted temporally through age group and seasonal variation. One particular participant who had suffered previous injuries to their ndom (left) hamstring and quadriceps within the 12 months prior to the study (though he was considered fully fit at the time of testing and was participating in all aspects of football activity) would have been considered 'at risk' according to the preintervention isokinetic testing session as their PTBW CH, and EH, CHQ, FHQ, CQ:CQ, CH:CH and EH:EH were more than one standard deviation lower than the cohort mean, and also fitted the identifying features of Crosier and Crielaard (2000). In contrast to one representative member of the intervention group, the effect of the intervention strategy for this participant was to substantially improve PTBW EH performance on both legs (mean of dom and ndom approx 0.65

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which may be considered meaningful (Table 3.2, pp 68), substantially move AoPT EH toward outer range (mean of dom and ndom 35° which may be considered meaningful (Table 3.1. pp 68) and substantially improve CHQ and FHQ (mean of dom and ndom approx 0.12 for CHQ, and 0.45 for FHQ which may be considered meaningful (Table 3.2, pp 68). These improvements all constitute improvements in factors linked to increased hamstring injury risk and therefore it may be suggested that a targeted approach was effective. Of note however, was the fact that this participants 'at risk' profile for asymmetry was not substantially attenuated by the intervention. Thus, the bilateral nature of the exercise intervention does not seem to have been appropriate where a unilateral functional deficit existed. Overall the comparison of randomised vs. targeted exercise intervention was of interest because it suggests an intensive and magnified effect for the exercise intervention study and may link to the clinical practice of coaches, clinicians and trainers who are interested in evidenced based medicine.

# 7.5. Limitations

It was unfortunate that the present study failed to blind the control group to the activity undertaken by the exercise intervention group. As a result it was suspected that some of the control group perceived the exercise intervention as beneficial may have undertaken aspects of it away from the club training facility, leading to diffusion and contamination. This would appear to be important for all of the variables evaluated and may be an important reason as to why the hypotheses were rejected. Another limitation was the small sample size; this limited the generalisation of results to the rest of the youth football population. Furthermore a low sample size may lead to the possibility of a type II error meaning that the hypothesis was incorrectly rejected. Further research should aim to complete subsequent studies using large participant groups where diffusion is effectively controlled.

Another limitation was that the exercise intervention applied, while targeted to both age group and time during the season, was not targeted to individual weakness or dysfunction. This might have meant that the exercise intervention had variable intensity and yielded differing levels of adaptation within the experimental group. This may have contributed to the lack of between group differences because some members may have benefited where others did not. Thus, a possible recommendation for coaches, clinicians and trainers is to complete pre- exercise intervention testing and prescribe appropriately based on the results.

A final limitation was that the comparison of randomised vs. targeted approach to exercise intervention was only undertaken using an informal case study. This meant that the findings have

limited transferability and represent a fairly low level of evidence. Indeed, it should be noted that since no control intervention was applied in this analysis it cannot be said that the exercise intervention used was more successful than any other type of exercise.

# 7.6. Conclusions

It was evident that the exercise intervention can be effective to modulate perceived 'risk' factors for hamstring injury such as decreased PTBW, H: Q imbalance, and an inner range AoPT EH when used in conjunction with normal early season training. However, the dose-response relationship of exercise to adaptation appears to be specific to the population at hand, meaning that intervention programmes for elite youth footballers should be of 10 weeks or longer. It was also evident that the dom and ndom leg did not show similar adaptations as a result of the bilateral intervention and therefore training status, and leg dominance of participants as well as the type and overall regimen of exercise prescribed should be considered as part of the intervention planning process. As such the findings may be of interest to coaches, clinicians and trainers who prescribe preventative and restorative hamstring exercises for this population. Of further interest was the fact that a targeted intervention did appear to show an additional benefit to a randomised approach. Since, the aim of preventative exercise is to gain specific adaptation where required this may suggest that a 'one size fits all' approach to injury prevention is not ideal, even if the intervention appears appropriate to both age and seasonal variation. Further research which considers risk factors using more targeted approaches may be warranted.

# **Chapter Eight: General discussion and conclusions**

## 8.1. Discussion

The current project aimed to provide information necessary to assist in solving the injury problem in youth football. In order to achieve this aim, the experimental chapters first sought to discover the muscular strength and performance characteristics of the players of the English youth game as they age both chronologically and biologically. It was next important to highlight temporal patterns for heightened injury risk throughout chronological and biological ageing throughout the competitive season. It was hoped that injury risk may be attenuated through preventative exercise intervention, and therefore the final experimental chapters sought to investigate the efficacy of that exercise. It was anticipated that the findings of the current project would be of use to coaches, clinicians and trainers who work with youth footballers on a day to day basis. Thus, it was the purpose of this final chapter to provide context for the five experimental chapters of the thesis, and to review their importance both clinically and academically in light of relevant literature and the specific objectives of the project. A further aim was to discuss the potential limitations to the current project, and the directions for future research.

# 8.1.1. Discussion of objectives

The first objective of the current project was to investigate the specific pattern of isokinetic muscular strength (PT/PTBW) and performance (H:Q, dom:ndom and AoPT) for elite male English youth footballers. In Chapter Four this objective was met because there was clear information and knowledge added about chronological and biological age group muscular strength and performance in a large cohort of elite male youth footballers. The major finding was the move toward muscle imbalance (FHQ) shown by the U18 age group in comparison to the younger age groups. This illustrated the importance of targeting this age group as being at an increased risk of injury, which had not been reported as significant in previous research (Ellenbecker et al., 2007; Ahmad et al., 2006; Barber-Westin, Noyes and Galloway, 2006; Gerodimos et al., 2003; Kellis et al., 2001). A further finding was the significant bilateral hamstring asymmetry noted for the youngest age groups. Analysis of asymmetry has seldom been undertaken before, though parallels may be drawn to the recent work of Fousekis, Tsepis and Vagenas (2010) (pp 53) regarding the effect of training history on asymmetry, and the interaction between training, asymmetry, performance and injury in adult footballers. This was of interest for the remainder of the current project, though the specific cause and effect of this relationship, for example did youth footballers 'adapt' muscularly to football, or did those who were previously 'adapted' muscularly become youth footballers, or a combination, remained to be elucidated.

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In Chapter Four the relative merits of normalising PT to BW also became apparent. Differing patterns of contraction specific hamstrings and quadriceps strength development were observed, though football specific strength patterns were illustrated in agreement with previous research for both PT and PTBW (Kellis et al., 2001; Chin et al., 1992; Rochcongar et al. 1988). This finding meant that PT gave no additional information over and above PTBW and was therefore not used further in the project. A further methodological determination was that in agreement with previous literature (De Ste Croix et al., 2002; Segar and Thorstensson, 2000; Maffulli, King and Helms, 1994), no independent effects could be determined for biological ageing in comparison to chronological ageing. Thus, biological age grouping only remained of interest for the Chapter Six which directly concerned injury, as was the case for AoPT which, as expected, showed no consistent relationship with ageing.

The second objective of the current project was to determine the seasonal variation of muscular strength and performance factors across a competitive season. This was to inform coaches, clinicians and trainers of periods which might constitute times where risk attenuation strategies might be best placed through organisation of training. Periods of peak injury incidence across the course of the competitive season of English youth football were observed by Price et al. (2004). These authors cited that months following breaks from football activity were characterised by significantly higher injury incidence, with training injuries peaking in January and August. In Chapter Five the current project provided information regarding, muscular strength, which could prove useful to partially explain this phenomenon. A MS (January) drop in PTBW was noted for the hamstrings and quadriceps in both contraction types. This was not expected because an MS drop in performance had not been observed isokinetically, nor using other types of measurement except in Junior Rugby league (Gabbett, 2005b). However, this may be due to the distinct lack of longitudinal isokinetic data which was highlighted throughout the current project. A MS drop in muscular strength was important because it may be preventable through the manipulation of conditioning goals and the use of preventative exercise as discussed in later chapters.

No distinct seasonal variation was found regarding muscular performance in Chapter Five. This was potentially due to the relative nature of muscular balance and asymmetry, but also the inherently complex nature of growth and maturation and how this may affect AoPT which has yet to be determined. The lack of seasonal variation for muscle balance, specifically FHQ was of particular interest when viewed alongside the findings of Chapter Four. Thus it may be that EH strength deficit, which may cause muscular imbalance, may be the important risk factor rather than the presence of FHQ imbalance. Therefore, the finding that youth footballers failed to progress their PTBW EH to the same extent as concentric hamstrings and quadriceps may be the source of the FHQ concern noted earlier. Furthermore, if coaches, clinicians and trainers wish to

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attenuate injury risk there may be an argument to target hamstring strength rather than setting out to ascertain muscular imbalance and intervene as correction may be achieved through weakening the quadriceps leaving the injury risk unattenuated. Further important findings from Chapter Five were that no chronological age differences were found for seasonal variation. This was probably to be expected because Chapter Five only included participants from the U12 to U15 age groups due to the logistical impossibility encountered in tracking U16 and U18 participants. U16 and U18 are inherently transient and traditionally move clubs and/or give up football at these times. This meant that despite the U18 age group being selected as a 'risk' period for injury, the seasonal variation link to injury incidence could not be made for this age group.

The third objective of the current project was to understand the problem of injury in youth football and its relationship with muscular strength and performance for the population of interest. As a result of the review of literature (Chapter Two) it was accepted that muscular strength and performance of the hamstrings and quadriceps was only one of a myriad of factors which might influence injury risk and incidence in youth football. It was shown in Chapter Six that isokinetic analysis of muscular strength and performance of youth footballers may yield information regarding the effect of injury, because variables such as PTBW and AoPT of the hamstrings were retrospectively negatively linked to a history of injury incidence. However, muscle balance and asymmetry did not appear to be linked to injury which was in contrast to some other authors (Orchard et al., 1997). Unfortunately, the research design for Chapter Six did not allow for discussion of a cause and effect relationship due to low subject numbers and injuries in the prospective study. It remains of interest to discover whether history of injury caused the noted deficits in PTBW and inner range AoPT, or whether these factors were already present and preceded injury. This is of importance because stage two of van Mechelan, Hlobil and Kemper's (1992) sequence, where injury aetiology and mechanism is established could not yet be considered complete.

An interesting point for further discussion concerns the use of logistical regression analysis for injury aetiology research. The current project was only the second to the author's knowledge to utilise this technique with reference to injury in football (the other paper being Fousekis et al., 2011). This method for predicting the category (injured/non injured) to which an individual is likely to belong given relevant other information (Field, 2009) may have beneficial implications. This is because the researcher is able to apply a level of clinical reasoning to the research design by utilising factors which could be postulated as 'risk' factors both independently, and in unison. Furthermore, the statistical technique appears to accurately reflect the fact that injury aetiology is undoubtedly multi-faceted.

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The fourth objective of the current project was to ascertain whether highlighted injury risk factors for muscle strain injury could be modulated by an exercise intervention compiled from the programmes shown to be effective by previous research. This was achieved through a study of the effects of an exercise intervention programme targeting the hamstrings which was outlined in Chapter Seven. This chapter formed a culmination of the information gathered from the first three experimental chapters because the U18 age group were utilised as participants as suggested by Chapter Four. In addition, the exercise intervention also took place in the months of July and August in an attempt to target any possible muscle strength deficits caused by time away from football activity during the off season as suggested by Chapter Five. Chapters Two and Six informed both the target musculature and the nature of the exercise intervention. This was because hamstring strains were found to be the most common injury in English youth football (Price et al., 2004) and were the most common type of muscle strain injury in the participants of Chapter Six. Furthermore, the nordic lower exercise, and F11 have been suggested to decrease injury incidence and risk through the attenuation of isokinetic injury risk factors such as inner range AoPT, hamstring strength deficits, imbalances and asymmetries (Brito et al., 2010; Arnason et al., 2007; Beneka et al., 2005; Clark et al., 2005; Proske et al., 2004; Askling, Karlsson and Thorstensson, 2003; Mjolsnes et al., 2001; Brockett, Morgan and Proske, 2001; Kaminski, Wabberson and Murphy, 1998).

The main finding from Chapter Seven was that the exercise intervention appeared to positively attenuate injury risk factors. However there was not enough evidence to suggest that this effect was independent of early season training for youth footballers. The control and intervention groups did not differ significantly post intervention and thus the trend for greater improvement in the intervention group could have been as a result of chance alone. Another potential reason was that allocation of participants to group via FHQ performance did not allow for targeting of the intervention exercise to those participants who may be considered at risk of muscle injury strain. This premise was investigated as part of the discussion of Chapter seven because an objective of the current project was to link research to practice, something which is considered core in the doctrine of evidence based medicine. Thus, the final experimental chapter reminds the researcher of the value of injury risk screening, and in addition the usefulness of acting upon that information using a combination of both clinical and research principles.

# 8.1.2. Summary of the project

In its entirety the current project highlighted the merits of a logical and progressive approach to the investigation of injury prevention within a distinct population. In overview, despite the complexities surrounding injury, injury prevention, ageing, growth, maturation and muscular

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strength and performance, it was possible to identify some clear 'take home' messages for coaches, clinicians and trainers.

Yearly age group distinctions between playing levels of youth football remain appropriate from intrinsic and modifiable injury risk perspectives as once BW was controlled there were only significant differences in muscular strength every two-three age groups (with the exception of PTBW EH and the consequences of this discussed in Chapter Four). Furthermore, the MS performance decline which was noted was not particular to age group status. Finally, the differences between injury incidence which was discovered in later chapters was markedly apparent between age categories rather than age groups. This was important because to the present author's knowledge no one body of work has considered the strength and muscular performance of youth footballers with reference to several temporal factors such as chronological and biological ageing, and seasonal variation. These factors were revealed to have interrelationships with strength and muscular performance and injury, though it was not possible to decipher the distinct influences of biological and chronological ageing within the scope of the current project. A possible explanation for this was that the assessment of biological age used in the current project did not make reference to those participants who may be biologically 'advanced' or 'delayed' in comparison to their age group. These participants are considered to be at a greater risk of injury than 'normally' maturing individuals (Johnson, Doherty and Freemont, 2009; Le Gall, Carling and Reilly, 2007). Thus, this may be a focus for future research.

There also appears to be much to learn regarding the nature of youth footballers and leg dominance; specifically, the relationships between muscular strength and performance, injury, ageing and dominance. Throughout several chapters younger age groups were seen to have greater PTBW CH on the dom leg resulting in CH:CH asymmetry, the dom leg was also most often injured (Hx and Hx12), and showed a relationship with previous injury of the hamstrings regarding strength deficits (CH and EH) and altered AoPT CH which was not present for the ndom. However the concept of dominance in 'trainability' and skill acquisition has not yet been adequately elucidated, despite interesting recent research into the area by Fousekis, Tsepis and Vaganas (2010) concerning adult footballers. To this end, the current project may be a starting point to initiate specific projects in this area regarding the biomechanical and skill acquisition effects on strength and muscular performance throughout youth.

A final major finding was that the cycle of prevention (van Mechalen, Hlobil and Kemper, 1992) could be usefully applied to youth footballers which has seldom been completed in previous research. However, in order to maximise the value of this approach there were factors which should be given consideration. The causation of injury for youth footballers must be considered to be multi-faceted, though in the current project hamstring strength deficits and muscular

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performance dysfunctions did show links with injury risk. This was characterised by what appeared to be a football specific EH PTBW deficit as chronological ageing progressed, decreased PTBW CH in previously injured players and altered AoPT CH. These factors may all be targeted for risk attenuation through exercise according to the cycle of prevention (van Mechalen, Hlobil and Kemper, 1992) yet the results of the exercise intervention study suggested that temporal targeting (age, time) could be made more effective. Thus, a major finding of the current project was that a pre-intervention screen for hamstring strength and asymmetry should be considered essential. This would allow an approach which can be tailored to the risk factors which are pronounced based on injury history and possible relationships as well as what may be expected for an individual's chronological age, sport demands and normative data.

## 8.2. Limitations

The limitations which were particular to each experimental chapter have been discussed as part of those chapters where appropriate. However, it was also relevant to consider the limitations of the current project in summative form before the conclusions were presented.

A limitation which affected the entire project was some of the detail of the isokinetic methodology employed throughout. There has been suggestion that seat compression of the isokinetic dynamometer and alignment/calibration of the participant with relaxed musculature may affect reliability and error during testing (Baltzopoulos et al., 2012), particularly for measures of AoPT. This was not controlled for in the current project study and may have contributed to the variability of the sample as outlined in Table 3.1 (pp 68; where PT and AoPT are compared). Though the inclusion of analysis of this variability minimised the chance of type 1 error as a result, this still represents a limitation which could be better controlled for in future research. Another suggestion is that H: Q ratios such as CHQ and FHQ should be angle-specfic (Aagard et al., 1998). This was not the case in the current project and as such probably affects the transferability and external validity of the results because CHQ and FHQ from averaged repetitions, but from any point in the ROM, may not give the required insight into the torque of the muscle through its actual function as the hamstrings and quadriceps move between inner, mid and outer range respectively. The current project does have high comparability with previous literature as a result of not specifying to this variable, however, future research may wish to control for this limitation in order to make more explicit links between muscle function and injury risk.

Another limitation was that the youth football population, which has inherently complex physiology caused by the concurrent processes of growth and maturation, may have been evolving at a faster rate than was possible to record in the current project. Thus, it may be that

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particular interactions between biomechanical factors such as lever arm length increase through long bone growth which may affect strength went unnoticed and uncontrolled. Furthermore, muscular strength may have been affected by interactions between the hormones which underpin the process of maturation and this was also not controlled within the current project. Despite these factors, the effects of maturation were considered to some extent through the inclusion of PDS grouping. It is acknowledged that this is a self-report measure and may lack the specificity and accuracy of objective biological age assessment. However, it was accepted that the scope of the current project would only consider the functional outcomes of underlying cellular activity of maturation such as: bodily hair growth, physique alteration, vocal changes and muscular strength and performance development.

It may also be considered a limitation that the specific football demands (training and game) placed upon the participants in the current project were not recorded. Chapter Two accepted that strength adaptations may be mediated in this way and so understanding this specifically would have been an advantage. Particularly since there were two CoE which provided participants for the current project, and despite working within a broad curriculum the coaches are unlikely to have delivered very similar football training sessions and/or match strategy and tactics. Recording of this nature would also have allowed for much greater specificity regarding the effect of injury in the population because it would have been possible to record 'missed' football activity. This limitation also affected the current project because it was not possible to make direct inferences about the exercise intervention to actual incidence of injury after the study. This was originally to be attempted as part of the current project but became logistically impossible without the required input and support from the medical staff of the clubs involved. Thus, the only acceptable course of action was to make links to firm empirically cited risk factors for injury using the research of others.

A final limitation concerned the progressive reasoning employed throughout the current project. Only the U12 to U15 age groups were used as participants for Chapter Five which highlighted the MS drop in PTBW for the hamstrings and quadriceps. Despite this, this U18 age group were targeted for the intervention in Chapters Seven and Eight using the reasoning that they might also encounter this pattern of seasonal variation. This was largely due to the findings of Price et al. (2004) who noted a peak in injury incidence after breaks from football activity in all age groups up to U20. It was therefore accepted that this reasoning was not directly supported by the findings of Chapter Five, even though the information gathered regarding strength deficit of EH and imbalance of FHQ gathered in Chapter Four did provide direct support for the use of the U18 age group. As such it may be a consideration for future research to seek to confirm the existence of a MS drop in all of the age groups of youth football.

#### 8.3. Future research

There were three areas of immediate concern for future research as a result of the current project. The first, would be to design a study which can answer the question of whether football training, or self selection on the part youth footballers, affects muscular strength and performance. This question may only be answered by controlling the effects of chronological, and to a lesser extent, biological ageing and then comparing muscular strength and performance by years of youth training history. This project may even be possible using the data collected as part of the current project.

A further area for future research would be to confirm the effect of seasonal variation (a MS drop in strength) which was reported in Chapter Five. In order to achieve this isokinetic evaluation should be undertaken more frequently than three times across the season, and also for multiple consecutive seasons. This may account for any variations in growth and maturation which may have been missed by the longer time frame used in the current project. This would also allow the author to answer the question of whether the drop was indeed related to a 'break' from football activity and if so how long a break causes said effect.

A final area of further interest would be to link the results of the current project more directly to injury incidence as opposed to injury risk factors. A possible future project to meet this need would be a prospective design similar to that used in Chapter Six using logistic regression analysis. The multi-factorial nature of injury aetiology could be addressed by pre-season screening of isokinetic muscular strength and performance as well as ROM, injury history, and other subjective factors such as movement screening and dysfunction. This would require input and 'buy in' from club medical staff because injury logs and time lost from training and injury would need to be recorded throughout the season to allow an effective research design.

## 8.4. Conclusions

The conclusions of the current project were that youth footballers may be expected to report a pattern of muscular strength and performance which is sport specific. This may be of value for normative data purposes, but also demonstrated that youth footballers did not develop their eccentric hamstrings strength in line with their concentric quadriceps and hamstring strength. Analysis of this effect across chronological and biological age groups, as well as across the course of a competitive season of youth football suggested that eccentric hamstring strength deficits led to areas of concern for the U18 age group and at periods of football activity which immediately follow breaks or 'rest' periods. Asymmetry in hamstring muscular performance may also be expected from the younger age groups of youth football, though the current project was not able

to determine whether this was as a result of football training or a trait inherent in younger participants who take up the game.

Finally, it was clear that hamstring muscle strains were common in youth football. However, evidence based exercise intervention strategies, while targeted to temporal periods of 'need' (age and seasonal) were not sufficient to bring about significant improvements in hamstring strength and muscular performance. Nonetheless, targeting the same intervention to individuals who appear 'at risk' through using isokinetic evaluation as an injury risk screening tool appeared to show promise, as did the use of a logistic regression statistical technique.

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# Appendices

Appendix A: Information sheet for experimental chapters 4, 5 and 6

Appendix B: Example of informed consent used for all experimental chapters

Appendix C: Example of pre exercise medical questionnaire used for all experimental chapters

Appendix D: The pubertal development scale questionnaire

Appendix E: Injury report form for chapter 6

Appendix F: Information sheet for chapters 7 and 8

Appendix A

University of Hull Department of Sport, Health, and Exercise Science



# PARTICIPANT INFORMATION SHEET

Project Title	Fitness and Injury risk in Elite male youth footballers	
Supervisor/Director of Studies	Remco Polman	
	Jason Siegler	
Principal Investigator	Hollie Forbes	
Purpose of Study and Brief Description of Procedures		
(Not a legal explanation but a simple statement)		

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Lars McNaughton, Chair of the Department of Sport Science Research Ethics Committee (Tel: 01482 466927) who will undertake to investigate my complaint.

## Information for participants and parents

The testing programme outlined below aims to assess soccer specific endurance and fatigue using a new test called the soccer specific agility and fitness test (SAFT). Players involved with the study will also undergo a comprehensive fitness review which will provide information to the club and university regarding: injury risk markers, growth, maturation and development, talent identification, and physical, psychological and anthropometric factors. Some of this information will then be related to any injuries that occur over the subsequent seasons play in order to inform future injury prevention programmes.

Testing will take place at the applied physiology and biomechanics labs at the University of Hull, directions to the University are provided with this pack.

A timetable of testing throughout the season will be provided for you by the club, however, it is expected that you will be asked to attend the University twice on two consecutive evening sessions, in the months of September, January and April. Each session should last approximately 3 hours maximum.

The researchers involved in this study are listed in the contact information sheet included with this pack. You should be assured that any direct contact and analysis of sensitive data will be conducted by student and staff members who have been checked by the criminal records bureau (CRB).

You are free to ask questions or to withdraw from participation at any time.

#### The tests

The tests are arranged into four separate sessions, each contains a variety of tests which are designed not to impact upon each other. The table below outlines the content of each session.

Session 1	Session 2
<ul><li>SAFT test</li><li>Body composition</li><li>Height and Weight</li></ul>	<ul> <li>Maximal vertical jump</li> <li>30m Sprint</li> <li>Repeated sprints</li> </ul>
Session 3	Session 4
<ul><li>Posture and Flexibility</li><li>Isokinetics</li><li>Balance and Stability</li></ul>	<ul><li>VO2 Max</li><li>Lung Function</li><li>Questionaires</li></ul>

N.B. please be aware that sessions three and four may interchange for some participants as they will run concurrently over both scheduled evenings.

#### Description of tests and procedure:

#### Soccer-specific Aerobic Fitness Test (SAFT)

The SAFT test measures soccer specific aerobic performance, it is performed indoors and is similar to the traditional bleep test. The SAFT course is 20m long and includes forwards, backwards, and lateral movements. The pace of the test is dictated by a CD and you should aim to keep pace with the beeps until you can no longer continue running or keep pace. Before the test begins you will warm up and familiarise yourself with the course. You will also have the rules of the test explained to you and be given an opportunity to ask questions.

#### **Body Composition**

Body composition analysis gives information of the physical make-up of the body, specifically the proportion of fat. For this testing you will be required to remove your shirt. Measurements will be taken twice using callipers (a device for measuring skinfold thickness) at sites on your arm, leg, back and hip. The procedure will cause very little discomfort; however, you are free to withdraw at any time.

#### Height and weight

For your weight measure you will be asked to wear only your shorts and t-shirt, no shoes. Firstly, you will then be asked to stand on a low set of scales and secondly, next to a height pole.

#### Maximal Vertical Jump (MVJ)

The MVJ tests lower limb power production. Testing will take place using a jump mat placed on the floor. A researcher will demonstrate how the test is to be performed. You must keep your hands on your hips at all times and aim to jump as high as you can. A researcher will calculate and record the height of your jump. You will then be asked to repeat the jump three times.

#### 30m Sprint

The sprint tests give information as to speed and acceleration. You will be asked to sprint forwards, as fast as you can, for 30m along a course set out by cones and pairs of timing gates. You will be asked to start from a standing start and a flying start.

#### **Repeated Sprints**

Repeated sprints give information of agility, agility endurance and fatigue. You will be asked to complete a sprint agility course. The specific route to take through the timing gates will be explained to you before testing begins however, you will be asked to run forwards through timing gates and turn 180 degrees at times. The course will be completed five times with one minute rest between runs.

#### Lower back Posture (LBP)

Lower back posture has been associated with an increased risk of hamstring injury and lower back pain. Analysis will give information as to the effect of ageing on these variables. LBP will be assessed using a device called an inclinometer. A researcher will first mark points on your spine, then you will be asked to stand relaxed while measurements are taken corresponding to these marks. This testing will cause no discomfort, however, you will be asked to remove your shirt.
### Flexibility

The flexibility tests will concentrate on the muscles at the front and back of the thigh; a lack of flexibility in these muscles has been linked to an increased risk of muscle strain injury. To measure flexibility accurately a researcher will first mark four points on the outside of your body and legs, you will also be asked to complete a cycle warm up of 5 mins. Flexibility will be then be measured using a goniometer. You will be asked to lie on either your front or your back on a treatment bed and move both legs into positions explained to you by the researcher. You will be in control of all movement, however, you should feel a stretch in your hamstrings and quadriceps.

#### Isokinetics

Isokinetic measurement gives information regarding muscle strength, in this case those which surround the knee. Strength variables can be important in improving performance and decreasing risk of injury. Testing will take place using the isokinetic dynamometer which is a seated device commonly used in both performance testing, and injury rehabilitation and prevention. You will familiarise yourself with the protocol after you have completed the SAFT test in session 1. The test involves being strapped into the chair on the machine and you will be asked to complete movements but only on one leg. The movements will involve kicking your leg or pulling your heel inward, however, this will be explained by the researcher more fully before the test begins. In full testing, both legs will be assessed and all of the movements will be repeated 5 times, you will also be asked to complete a 5 min cycle warm up. None of the movements should be painful but you should try as hard as you can.

#### **Balance/Stability**

A lack of balance and stability may lead to injury therefore this testing will give information which is important for injury prevention. You will be required to perform a 5 min warm up on a cycle before you begin this testing. You will be asked to stand on one leg then the other, on a Biodex balance platform. The platform will be unlocked and will become unstable, you should try to keep as still as possible for 10 seconds; this will be repeated on each leg 3 times. The platform is surrounded by supports so there is little risk of falling over, however, if you are uncomfortable you can remove yourself from testing.

#### VO2 Max

Vo2 Max testing gives information concerning how much oxygen your body can take in from the atmosphere and use. This may be important for football performance and is certainly important for fitness. The test takes place on a running treadmill and increases in intensity and speed as the test progresses. You should aim to increase your speed along with the treadmill until you can no longer keep pace. During the test you will be required to wear a mask on your face which will collect the gases you are breathing; this allows the calculation of Vo2 max to take place. You should be aware that the mask will not interfere with your normal breathing. The vo2 max test will finish when you lift yourself off the treadmill using the handrails, the person administering the test, however, you may chose not to undertake the test without prejudice.

#### Lung Function

Lung function testing will allow researchers to analyse the capacity of your lungs. This information may be interesting when comparing age groups. This test does not require any exercise. You will be asked to take a deep breathe in and out, and then exhale as forcefully and quickly as you can into a machine called a spirometer. The spirometer will give a measure of your lung function. You should be aware that the mouthpieces used on the spirometer will be changed between each participant.

#### Questionnaires

You will be asked to fill in two different types of questionnaire. One will ask you about events that have occurred in your life. The other will ask you about your physical development. This information is useful to researchers because it may allow us to identify some possible reasons as to why some people get injured, and also to estimate your physical development age which is not always the same as your chronological age. Some of the questions are personal, but you should be assured that no one will read your answers except the principal researchers and they will not be able to identify you because you will be given a subject number instead of using your name.

If after reading through this information sheet, you have further questions please contact Hollie Forbes who will try to answer any concerns you may have.

H.Forbes@hull.ac.uk 01482 465688

Appendix B

# **University of Hull** Department of Sport, Health, and Exercise Science



# Informed Consent Form

I have read the participant information sheet supplied by Hollie Forbes outlining the tests I am to perform.

## The participant should complete this sheet himself / herself

1.	Have you completed the pre-exercise medical questionnaire?	YES / NO
2.	Do you understand that your information will be treated as confidential?	YES / NO
3.	Have you read the participant information sheet?	YES / NO
4.	Have you had the opportunity to ask questions and discuss the test?	YES / NO
5.	Have you received satisfactory answers to all of your questions?	YES / NO
6.	Have you received adequate information about the test?	YES / NO
7.	With whom have you discussed the nature of the test?	
8.	<ul> <li>Do you understand that you may withdraw from the test:</li> <li>At any time</li> <li>Without needing to give reason</li> <li>Without prejudice</li> </ul>	YES / NO

9. I have read, discussed and fully understand the requirements, procedures, and potential risks involved in the test and give consent for my participation.

Signature	Date
Test Administrator	Date
Parent if Minor	. Date

## **University of Hull** Department of Sport, Health,

and Exercise Science



## Pre-Exercise Medical Questionnaire

This questionnaire should be filled in by you and your parents if you are under 16, all information in this document will be treated as strictly confidential.

Name: .....

Date of Birth: ..... Age: ..... Sex: .....

Height (cm): ...... Weight (Kg): .....

Please answer the following questions by putting a circle round the appropriate response or filling in the blank.

- 1. How would you describe your present level of **exercise** activity? Sedentary / Moderately active / Active / Highly active
- 2. Please outline a typical weeks exercise activity

3.	How would you describe your present level of <b>lifestyle</b> activity? Sedentary / Moderately active / Active / Highly active	
4.	How would you describe your present level of fitness? Unfit / Moderately fit / Trained / Highly trained	
5.	Have you had to consult your doctor within the last six months?	Yes / No
	n you answered <b>res</b> , have you been advised <b>not</b> to exercise:	Yes / No
6.	Are you presently taking any form of medication?	Yes / No
	n you answered <b>res</b> , have you been advised <b>not</b> to exercise:	Yes / No
7.	To the best of your knowledge do you, or have you ever, suffered from: <b>a</b> Diabetes?	Yes / No

<b>b</b> Asthma?	Yes / No
<b>c</b> Epilepsy?	Yes / No
<b>d 苯</b> Any form of heart complaint?	Yes / No
e * Any form of repiratory complaint?	Yes / No

8.	If you answered yes to any of the questions marked with a <b>*</b> please give further details here or consult a researcher			
9.	Do you currently have any form of muscle or joint injury? If you answered <b>Yes</b> , please give details	Yes / No 		
13.	Have you had to suspend your normal training in the last two weeks? If the answer is <b>Yes</b> please give details	Yes / No		
14.	<ul> <li>Please read the following questions:</li> <li>a)  Are you suffering from any known serious infection?</li> <li>b)  Have you had jaundice within the previous year?</li> <li>c)  Have you ever had any form of hepatitis?</li> <li>d)  Are you haemophiliac?</li> </ul>	Yes / No Yes / No Yes / No Yes / No		
	IF THE ANSWER TO ANY OF THE ABOVE IS YES:			
	Discuss with the test administrators or another appropriate member of the de	partment.		
15.	As far as you are aware, is there anything that might prevent you from successfully completing the tests that have been outlined to you? If you answered yes to the above, please explain further here:	Yes / No.		
	PLEASE SIGN AND DATE AS INDICATED			
	Participant Signature:DateDate			
	Test Administrator:DateDate			
	Parent if MinorDate:			

### HOW TO ANSWER THE CUESTIONS

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1.80

- Section I: To answer each question, please circle the number in front of the answer that best describes what is happening to you. Please choose only one answer for each question.
- 1. Would you say that your growth in height:
  - 1. has not yet begun to spurt ("spurt" means more growth than usual)
  - has barely started
  - 3. is definitely underway
  - 4. seens completed
- 2. And how about the growth of body hair ("body hair" means underann and pubic hair)? Would you say that your body hair has:

  - not yet started growing
     has barely started growing
  - 3. is definitely underway
  - 4. seems completed
- 3. Have you noticed any skin changes, especially pimples?
  - 1. not yet started showing changes
  - 2. have barely started showing changes
  - 3. skin changes are definitely underway
  - skin changes seem completed
- 4. Have you noticed a deepening of your voice?
  - 1. not yet started changing
  - 2. has barely started changing
  - 3. voice change is definitely underway
  - 4. voice change seems completed
- 5. Have you begun to grow hair on your face?
  - 1. not yet started growing hair
  - 2. has barely started growing hair
  - facial hair growth is definitely underway
     facial hair growth seems completed
- 6. Do you think your development is any earlier or later than most other boys your age?

15,537

- 1. much earlier
- somewhat earlier
   about the same
   somewhat later

- 5. much later

Section II: To answer each question, fill in the blanks with the best answer you can give.

7. How tall are you? Height: I am \_\_\_\_\_ feet and \_\_\_\_\_ inches tall.

8. How much do you weigh? Weight: I weigh \_\_\_\_\_ pounds.

### Appendix E

## Injury record sheet

V	We would like to know if you have been injured since you last visited the University for fitness testing.			
	Name: DOB Club: Age group:			
Ple	Please circle your answer unless asked to give detail. If you have had more than one injury please complete a second sheet and attach to the first.			
1.	Have you been injured since the last time you visited the university? Yes/No			
2.	When did the injury occur Training/Game/Slow onset			
3.	Did the injury happen with Contact (with player, etc)/No contact			
4.	<ul> <li>What were you doing when the injury occurred (i.e. running, tackling etc)</li> </ul>			
5.	Which part of your body was injured, (i.e. Head, front thigh, calf, forearm etc)?			
6.	Which side of your body was injured? Right/Left/None			
7.	Which side of your body was injured?Front/Back/None			
8.	8. What did the person treating you say your injury was called? Please write it below			
9	Have you ever had this injury before?			
J. 10	If ves when?			
11. How many training sessions did you miss because of this injury?				
12.	12. How many matches did you miss because of this injury?			

Thank you for filling in this form. Please sign and date below.

Signature:..... Date today:.....

### Appendix F

## **University of Hull** Department of Sport, Health, and Exercise Science



### PARTICIPANT INFORMATION SHEET

Project Title	H: Q ratios in youth footballers: effect of a specific training programme
Name of Participant	
Supervisor/Director of Studies	Jason Siegler
Principal Investigator	Hollie Forbes

### **Purpose of Study and Brief Description of Procedures** (Not a legal explanation but a simple statement)

(Not a legal explanation but a simple statement)

Purpose of the study: Thigh muscle imbalance has long been considered by researchers as a risk factor for muscle strain injury specifically tears/strains to the hamstring muscle group. Whilst being of great importance to acceleration and deceleration, the hamstrings also play a major role as stabilisers to the knee joint. With this in mind, maximising the function of these muscles may be considered important for injury prevention and performance. Hamstring muscle strains are one of the most common injuries seen in football which highlights a need for an effective preventative measure. Furthermore, hamstring strains are very likely to reoccur after any initial occurrence, thus increasing an injured individuals time spent away from training and play exponentially. An intervention which could decrease the likelihood of injury occurrence would aim to decrease the incidence of first time hamstring strains which would then have a knock on effect for reoccurrence rates, and time away from football. Past research has highlighted that a programme of eccentric exercise for the hamstring muscle group may be beneficial in redressing any thigh muscle imbalance which may be present, and furthermore may indeed decrease the risk of subsequent muscle strain injuries to the hamstrings. Our research has suggested that the U18 age group would be an ideal time to bring in such an intervention programme, since this was the point at which a significant shift away from hamstrings: quadriceps equality was noted.

**Procedure:** Participation in this study will require you to attend the University laboratory before and after a prescribed programme of exercise lasting 8 weeks. Upon arrival at the laboratory you will be required to complete a pre exercise medical questionnaire and informed consent form. You will then be measured for height, weight, and lower limb dominance (which leg you kick with).

### PRE & POST Exercise programme testing- Isokinetic dynamometer.

**Isokinetic dynamometer:** The isokinetic dynamometer measures strength through the whole range of a muscle, and allows researchers to control the speed at which your muscles perform specific actions. In this case your thigh muscles will be tested by setting up the equipment to measure bending and straightening your knee. Prior to measurement using the dynamometer you will asked to complete a five minute warm up on a static bike and will be given practice attempts on the dynamometer. Measurements will then be taken over 5-6 repetitions (of bending and straightening), on both legs, at slow and fast speeds. While you are completing the measurement sequence researchers will encourage you to try as hard as you Isokinetic data reduction.

**Exercise programme:** At your normal training facility you will complete at least two sessions of exercises each week, total number of sessions and attendance will be recorded. Sessions will take place post training. The exercises and their progressions are outlined below in Table 1.

Exercise	Week 1 -2	Week 3 - 4	Week 5 - 6	Week 7 - 8
The Bench	4. Hold for 15s	4. Hold for 20s	4. Hold for 25s	4. Hold for 30s
	5. Lift one leg	5. Lift one leg	5. Lift one leg	5. Lift one leg
	(15s)	(20s)	(25s)	(30s)
$\overline{O}$	6. Lift other leg	6. Lift other leg	6. Lift other leg	6. Lift other leg
	(15s)	(20s)	(25s)	(30s)
	Rest for 10s	between 1,2 and 3. Re	epeat twice	·
Bounding	30m x 2	30m x 3/4	30m x 5/6	30m x 7/8
$\sim$	2 min rest between	sets		
Nordic	2 x 6/8 reps	2 x 10/12 reps	3 x 6/8 reps	3 x 10/12 reps
Hamstring				
drop $\rho$				
'/	To incorporate lowering and pulling back components, progress to individual level			
	of control of angle of lowering. i.e. should get closer to 90° as progression			
	continues			

**Your rights as a participant:** Your participation in this study is voluntary. You are free to refuse to commence the testing or withdraw at any time in the proceedings without penalty or prejudice and without giving any reason for so doing. No disadvantage will arise from any decision to participate or not.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Lars McNaughton, Chair of the Department of Sport Science Research Ethics Committee (Tel: 01482 466927) who will undertake to investigate my complaint.

Table	1
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